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Contents for February, 1919

THE INHIBITION BY STABLE MANURE OF THE INJURIOUS EFFECTS OF ALKALI SALTS IN SOILS

C. B. LIPMAN AND W. F. GERICKE

California Agricultural Experiment Station

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When one sums up all of the investigations, and there have been many, which have dealt with the problem of control of alkali in soils, he is impressed with the large degree of failure in which these efforts have resulted. It is not our purpose here to review the whole situation and to comment on the probable causes for the failures to which we have referred. We merely wish to call attention now to the following facts. There have been two methods of attack for the problem. The first has concerned itself with inhibiting the toxic effects of the salts without removing them from the soil. The second has attempted to eradicate the evil by the total removal of the alkali salts from the affected soil. We hope at another time and place to discuss in detail the second method of attack, its *raison d'etre*, and its results. The first method or class of methods has been the subject of considerable investigation in this laboratory and has received some discussion at our hands. This class of methods comprises a number of sub-classes which it is unnecessary now to mention. It suffices for our present purposes to state that one of them consists in the use of easily decayed organic matter on alkali soils. This method of controlling alkali has, it is reported, frequently been crowned with success for short periods, at least when used by some farmers. The latter did not, of course, concern themselves with the causes or reasons for such protective action on the part of organic matter, but insisted that when barnyard manure was added to alkali soils, which permitted of only sparse plant growth, it effected marked changes in the soil and made possible good plant growth thereon. For some reason farmers have not been encouraged by experiment stations in the use, as a remedial measure, of barnyard and stable manures on alkali lands. It appears that a general impression of its practical inutility as an ameliorant for alkali soil has been abroad. It occurred to us in 1912 that the insistent claims of some farmers on the efficacy of manure on alkali land deserved some attention. Moreover, there appeared to be some sound theoretical basis, as we shall show below, for believing such claims to be correct.

PLAN OF THE EXPERIMENT

The experiment was conducted in a greenhouse. The plant containers were paraffined 9-inch earthenware flower pots, each of which received about 5 kilogram of soil. The soil used was a class or type commonly referred to as Berkeley clay adobe. It was collected on the campus of the University of California. The soil and manure used were both sifted through a $\frac{1}{4}$-inch mesh sieve. The dry manure and dry soil were thoroughly mixed in all pots in which manure was used. The amounts of manure used varied as shown in the accompanying tables. Duplicate cultures were run for all treatments, and control untreated pots to which no manure and no salt had been added were included in the experiment as well as control pots receiving the alkali salts but no manure. The salts were added in solution in the following amounts prior to the first planting: NaCl 0.3 per cent, Na_2CO_3 0.3 per cent, Na_2SO_4 0.6 per cent. Prior to the second planting, as much salt again was added, based on the dry weight of the soil, thus doubling the percentages just given. Losses of Na_2SO_4 were sustained through "creeping" in spots in which the pots had not been thoroughly paraffined. In the case of the other salts, however, there was no difficulty in maintaining the original salt content throughout the experiment.

Four successive crops were grown in the same pots in the following seasons: the fall and winter of 1913, 1914, 1915, and 1916. In order to allow for the so-called plant food substances added in the manure and make them equivalent so far as possible in all cultures, pots 1, 2, 3, 4, 5, 6, 7, 8, 17, 18, 19, 20, and 21 received applications of NH_4NO_3 and NaH_2PO_4. Thus, all pots receiving manure equivalent to 20, 40, 60, and 80 tons per acre and the two kinds of control pots above mentioned were so treated. The seed used was from a choice lot of seed of a selected variety of Beldi barley grown on the University Farm at Davis. The soil moisture was kept at the optimum as nearly as possible throughout the growing season. In harvesting, the straw, grain, and root yields were determined in every case except as otherwise stated below. The manure employed was in a very dry condition and contained only 25 per cent of moisture. The results of the experiment are given in the accompanying tables. We shall discuss separately the results obtained with every salt throughout the four seasons.

Series 1. NaCL

We are fully cognizant of the considerable variability which characterizes the values obtained by us from duplicate cultures both treated and untreated. Further, we are aware of the significance of such variability to the validity of conclusions drawn from the experiment. But with all this recognized, a study of tables 1, 2, 3 and 4 shows emphatically that organic matter in soils exerts a profound effect on the salts present with it, or that it so affects plant

growth on the soil as to make it proof against the toxic effects of the salts. The former is, of course, the more likely, but the latter is at least possible. Whatever the interpretation may be, it seems quite clear that organic matter, in sufficient quantity, exerts a protective effect on plants growing on soil containing NaCl.

In the first crop, in which it will be remembered the soil received only half the amount of NaCl that it did prior to growing the following three crops, 0.3 per cent NaCl gave a marked depression in the yield of dry matter, as is

TABLE 1

NaCl *series. First crop*

NUMBER	NaCl ADDED TO SOIL	MANURE RATE PER ACRE	WEIGHT OF STRAW	AVERAGE WEIGHT OF STRAW	WEIGHT OF GRAIN	AVERAGE WEIGHT OF GRAIN	WEIGHT TOTAL DRY MATTER ABOVE SURFACE	AVERAGE WEIGHT TOTAL DRY MATTER ABOVE SURFACE	WEIGHT OF ROOTS	AVERAGE WEIGHT OF ROOTS	WEIGHT TOTAL DRY MATTER	AVERAGE WEIGHT TOTAL DRY MATTER
	per cent	*tons*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
1	0.3	20	32.0	29.00			32.0	29.00	5.1	5.45	37.1	34.45
2	0.3	20	26.0				26.0		5.8		31.8	
3	0.3	40	44.1	45.25			44.1	45.25	8.2	6.75	52.3	52.00
4	0.3	40	46.4				46.4		5.3		51.7	
5	0.3	60	46.3	48.65			46.3	48.65	10.0	9.10	56.3	57.75
6	0.3	60	51.0				51.0		8.2		59.2	
7	0.3	80	45.0	53.70			45.0	53.70	6.2	8.10	51.2	61.80
8	0.3	80	62.4				62.4		10.0		72.4	
9	0.2	100	58.0	54.00			58.0	54.00	8.2	9.50	66.2	63.50
10	0.3	100	50.0				50.0		10.8		60.8	
11	0.3	120	66.0	55.50			66.0	55.50	6.0	7.10	72.0	62.60
12	0.3	120	45.0				45.0		8.2		53.2	
13	0.3	140	44.6	59.70			44.6	59.70	6.8	8.65	51.4	68.35
14	0.3	140	74.8				74.8		10.5		85.3	
15	0.3	160	55.0	61.00			55.0	61.00	8.0	7.00	63.0	68.00
16	0.3	160	67.0				67.0		6.0		73.0	
17	0.3		23.8	21.15			23.8	21.15	2.3	3.40	26.1	24.55
18	0.3		18.5				18.5		4.5		23.0	
19			47.0	42.50			47.0	42.50	6.7		53.7	50.47
20			40.0				40.0		11.7	7.97	51.7	
21			40.5				40.5		5.5		46.0	

indicated by a comparison of the yields of the untreated pots with those of the NaCl treated ones. When, however, to the soil containing 0.3 per cent NaCl manure is added at the rate of 20 tons per acre by weight, our data show that it inhibits the toxic effect of NaCl to a considerable degree. Moreover, when manure is added at the rate of 40 tons per acre or more, the toxic effect of 0.3 per cent NaCl is entirely obliterated and the cultures behave as if no salt were present in the soil. Indeed the larger applications of manure actually seem to add to their inhibitory effect a stimulating effect. With

regard to the latter point, it is of course difficult again to say whether the manure acts to prevent the toxicity of the NaCl or whether its stimulating effect on the plant is so great as to mask the toxic properties of the salt, thus yielding in the final results merely the algebraic sum of the stimulating effect of the manure and the depressing effect of the NaCl. However that may be, the net result of the manure applications, under the conditions studied, was to prevent partly or wholly, depending on the quantity used, the depressing effect on barley growth of the NaCl. As is usual under conditions of very

TABLE 2

NaCl *Series. Second crop*

NUMBER	NaCl ADDED TO SOIL	MANURE RATE PER ACRE	WEIGHT OF STRAW	AVERAGE WEIGHT OF STRAW	WEIGHT OF GRAIN	AVERAGE WEIGHT OF GRAIN	WEIGHT TOTAL DRY MATTER ABOVE SURFACE	AVERAGE WEIGHT TOTAL DRY MATTER ABOVE SURFACE	WEIGHT OF ROOTS	AVERAGE WEIGHT OF ROOTS	WEIGHT TOTAL DRY MATTER	AVERAGE WEIGHT TOTAL DRY MATTER
	per cent	*tons*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
1	0.6	20	10.00	9.23	7.00	6.77	17.0	16.00	2.20	2.10	19.20	18.10
2	0.6	20	8.45		6.55		15.0		2.00		17.00	
3	0.6	40	10.10	10.85	6.80	6.70	16.9	17.55	2.50	3.10	19.40	20.65
4	0.6	40	11.60		6.60		18.2		3.70		21.90	
5	0.6	60	21.80	21.96	13.20	8.79	35.0	30.75	2.90	3.40	37.90	34.15
6	0.6	60	22.12		4.38		26.5		3.90		30.40	
7	0.6	80	30.98	31.34	11.02	10.36	42.0	41.70	2.30	2.95	44.30	44.65
8	0.6	80	31.70		9.70		41.4		3.60		45.00	
9	0.6	100	45.70	46.31	11.80	11.09	57.5	57.40	2.00	3.20	50.50	60.60
10	0.6	100	46.92		10.38		57.3		4.40		61.70	
11	0.6	120	40.33	36.94	19.67	15.56	60.0	52.50	2.30	2.60	62.30	55.10
12	0.6	120	33.55		11.45		45.0		2.90		47.90	
13	0.6	140	40.05	40.71	20.15	18.89	60.2	59.60	2.75	2.58	62.95	62.18
14	0.6	140	41.37		17.63		59.0		2.40		61.40	
15	0.6	160	51.40	48.87	13.60	17.13	65.0	66.00	2.75	2.60	67.75	68.60
16	0.6	160	46.35		20.65		67.0		2.45		69.45	
17	0.6		16.90	10.20	1.10	3.05	18.0	13.25	1.98	1.24	19.98	14.49
18	0.6		3.50		5.00		8.5		0.50		9.00	
19			19.30		4.40		23.7	31.60	7.7	8.10	31.40	39.70
20			37.20		2.30		39.5		8.5		48.00	

heavy vegetative growth in our greenhouse, no grain was produced in the first crop. The root development followed, in general, the development of the tops, as the figures for the dry weight of roots indicate. Other points of interest in the first crop are common to all the series studied and will be discussed below.

In the second crop the doubling of the quantity of salt seemed to result in no greater depression in barley yield than that induced by 0.3 per cent NaCl. This is difficult to explain. On the other hand, the yield on the untreated

control pots decreased considerably; and the protective effect of manure applications at the rate of 20 and 40 tons per acre is apparent. This point is, however, very difficult of determination owing to the markedly discrepant values obtained from the duplicate cultures receiving only the 0.6 per cent NaCl without any manure additions. While, however, the question of the 20 and 40 ton applications of manure and their effects on the second crop is in serious doubt, there can be no question that the larger applications of manure are extremely effective, as they were in the first crop. When we

TABLE 3

NaCl *series. Third crop*

NUMBER	NaCl ADDED TO SOIL	MANURE RATE PER ACRE	WEIGHT OF STRAW	AVERAGE WEIGHT OF STRAW	WEIGHT OF GRAIN	AVERAGE WEIGHT OF GRAIN	WEIGHT TOTAL DRY MATTER ABOVE SURFACE	AVERAGE WEIGHT TOTAL DRY MATTER ABOVE SURFACE	WEIGHT OF ROOTS	AVERAGE WEIGHT OF ROOTS	WEIGHT TOTAL DRY MATTER	AVERAGE WEIGHT TOTAL DRY MATTER
	per cent	*tons*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
1	0.6	20	11.40	11.40	1.80	2.60	13.20	14.00	1.32	1.51	14.52	15.51
2	0.6	20	11.40		3.40		14.80		1.70		16.50	
3	0.6	40	14.10	14.10	4.10	4.20	18.20	18.30	1.04	1.15	19.24	19.45
4	0.6	40	14.10		4.30		18.40		1.26		19.66	
5	0.6	60	19.20	18.90	3.40	4.80	22.60	23.70	1.45	1.45	24.05	25.15
6	0.6	60	18.60		6.20		24.80		1.45		26.25	
7	0.6	80	21.75	20.60	7.25	6.70	29.00	27.30	1.20	1.38	30.20	28.68
8	0.6	80	19.45		6.15		25.60		1.55		27.15	
9	0.6	100	28.15	25.92	6.85	6.58	35.00	32.50	2.00	2.25	37.00	34.75
10	0.6	100	23.70		6.30		30.00		2.50		32.50	
11	0.6	120	41.10	39.10	12.30	9.40	53.40	48.50	2.24	1.87	55.64	50.37
12	0.6	120	37.10		6.50		43.60		1.50		45.10	
13	0.6	140	46.00	39.50	6.00	6.00	47.00	42.50	1.00	0.95	48.00	43.45
14	0.6	140	38.00		6.00		38.00		0.90		38.00	
15	0.6	160	26.25	33.02	3.75	6.28	30.00	39.30	1.30	1.67	31.30	40.97
16	0.6	160	39.80		8.80		48.60		2.04		50.64	
17	0.6		7.90	8.30	0.30	1.00	8.20	9.30	0.34	0.27	8.54	9.57
18	0.6		8.70		1.70		10.40		0.20		10.60	
19			8.05	11.95	2.15	1.45	10.20	13.40	1.95	2.48	12.15	15.88
20			12.80		1.20		14.00		3.26		17.26	
21			15.00		1.00		16.00		2.24		18.24	

consider the grain production alone and as separate from the straw yields, there seems to be no question that even the smaller manure applications are effective in preventing the toxic effects of the NaCl in the second crop. It should also be noted that with the increase in size of the manure application, its protective effect increases up to and including the 140 ton manure application. This is more true for grain than for straw production. Root production is depressed throughout in the second crop by the NaCl application, as is strikingly seen by comparing the root yields of the untreated pots with

those of all other pots in the series. Nevertheless, here again we find a definitely protective effect of the manure, as the figures indicate. But it should be noted that there is lacking the progressive increase in root production with increases in the size of the manure applications which characterizes the grain yields particularly, but to some extent also the straw yields in the same series.

In the third crop, the characteristic discrepancies between duplicate cultures are again in evidence. On the whole, however, the concordance between them is good, and it may be safe to assume from the data that evidence is at

TABLE 4

NaCl *series. Fourth crop*

NUMBER	NaCl ADDED TO SOIL	MANURE RATE PER ACRE	WEIGHT OF STRAW	AVERAGE WEIGHT OF STRAW	WEIGHT OF GRAIN	AVERAGE WEIGHT OF GRAIN	WEIGHT TOTAL DRY MATTER ABOVE SURFACE	AVERAGE WEIGHT TOTAL DRY MATTER ABOVE SURFACE	WEIGHT OF ROOTS	AVERAGE WEIGHT OF ROOTS	WEIGHT TOTAL DRY MATTER	AVERAGE WEIGHT TOTAL DRY MATTER
	per cent	*tons*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
1	0.6	20	10.50	10.50	4.50	4.65	15.00	15.15	4.00	3.95	19.00	19.10
2	0.6	20	10.50		4.80		15.30		3.90		19.20	
3	0.6	40	10.40	9.15	4.00	4.05	14.40	13.20	3.00	2.25	17.40	15.45
4	0.6	40	7.90		4.10		12.00		1.50		13.50	
5	0.6	60	8.00	10.43	2.00	3.82	10.00	14.25	2.70	3.35	12.70	17.60
6	0.6	60	12.85		5.65		18.50		4.00		22.50	
7	0.6	80	20.80	22.70	12.10	11.10	32.90	33.80	2.50	3.75	35.40	37.55
8	0.6	80	24.50		10.10		34.70		5.00		39.70	
9	0.6	100		18.10		10.60		28.70		4.00		32.70
10	0.6	100	18.10		10.60		28.70		4.00		32.70	
11	0.6	120	19.30	22.70	10.20	13.30	29.50	36.00	7.00	6.90	36.50	42.90
12	0.6	120	26.10		16.40		42.50		6.80		49.30	
13	0.6	140	30.00	32.00	15.00	14.50	45.00	46.50	6.50	6.75	59.50	53.25
14	0.6	140	34.00		14.00		48.00		7.00		55.00	
15	0.6	160	29.50	28.65	14.50	18.45	44.00	47.10	6.20	5.90	50.20	53.00
16	0.6	150	27.80		22.40		50.20		5.60		55.80	
17	0.6		6.90	7.15	2.20	2.20	9.10	9.35	1.30	1.35	10.40	10.70
18	0.6		7.40		2.20		9.60		1.40		11.00	
19			7.30	7.80	2.70	3.73	10.00	11.53	4.50	5.17	14.50	16.70
20			8.90		4.20		13.10		7.00		20.10	
21			7.20		4.30		11.50		4.00		15.50	

hand of the definite depression in barley growth produced by 0.6 per cent NaCl in this crop. The protective effect of the manure is even more certainly shown, and the evidence for it is in this instance certainly beyond question. As was true in the case of the second crop, there is in the third crop the progressively increasing protective effect with the increase in the quantity of manure applied up to and including the cultures receiving the 120 ton application. Applications greater than that seem to be without effect in increasing the yield. While thus we have evidence of the increase in its effects at

least up to a certain amount accompanying the increase in the amount of manure employed, it is also clear that even the smallest application used was distinctly effective. The marked protective effect noted, while applying in general to the dry matter production is, however, more true of the grain yields than of the straw and root yields.

In the fourth crop, as in the second, there is insufficient evidence on which to claim the depressing effect on straw production in the clay adobe soil of 0.6 per cent NaCl, but there seems to be no lack of evidence of such effect on the grain and root yields. As was true in the third crop, there can scarcely be any doubt that manure applications of all magnitudes exert inhibiting effects to the action of NaCl. Again the effects are much smaller with the three smaller manure applications but they are very marked with applications of 80 tons or more per acre, and increase from that through the higher applications reaching a maximum at the 140 ton applications. The grain yields and straw yields seem to be improving from crop to crop, and this seems to be true particularly from the third to the fourth crop.

Series 2. Na_2SO_4

Tables 5, 6, 7 and 8 give the results obtained with the 4 successive crops of barley in the Na_2SO_4 series. The amount of Na_2SO_4 used with the first crop (0.6 per cent) was evidently not great enough on the clay adobe soil to give any indisputable depression to the growth of barley. This is particularly true for straw production alone in the figures, from which in table 5 there is no evidence that the salt application definitely depressed the yield below that in the untreated control pots. In the root yields of the same crop, however, the evidence seems pretty reliable as a guide to the conclusion that 0.6 per cent Na_2SO_4 does definitely depress the root development of the barley plant on the clay adobe soil. No grain having been produced in the first crop of the Na_2SO_4 series, as was the case in the corresponding crop of the NaCl series, there is little cause for further comment on table 5. It is interesting to note, however, that while there were some differences between their effects, the different manure applications did not seem to make corresponding differences in the yields obtained. Another point is worthy of note here and that is that so large an amount of Na_2SO_4 as 0.6 per cent should be so slightly effective (roots) and so ineffective (straw) in regard to depressing plant development. It is very clear that in the soil with which we are dealing there is a factor of a strikingly inhibiting character to the effects of Na_2SO_4 on the barley plant. This factor must be the large internal surface offered by the clay adobe soil by means of which the salt is so largely adsorbed. It can scarcely be accounted for in any other way but it is not improbable that antagonism plays a large part here. It cannot be the resistance of the barley plant, since the latter from the same strain of seed when grown on a light soil is profoundly depressed by much smaller quantities of Na_2SO_4.

With the doubling of the quantity of Na_2SO_4 preceding the second crop, we note in table 6 what seems to be a very definite depression in yield due to the salt, despite the great discrepancy between the yields of the duplicate untreated control pots. The justification for the latter qualification may be found in the figures for the yields obtained in the pots receiving the smaller manure applications. All these statements apply fairly to the straw yields and very definitely to the root yields, but not to the grain yields. In the latter, we not only see no depression due to the effects of the Na_2SO_4 but there

TABLE 5

Na_2SO_4 *series. First crop*

NUMBER	Na_2SO_4 ADDED TO SOIL	MANURE RATE PER ACRE, SURFACE AREA	WEIGHT OF STRAW	AVERAGE WEIGHT OF STRAW	WEIGHT OF GRAIN	ANERAGE WEIGHT OF GRAIN	WEIGHT TOTAL DRY MATTER ABOVE SURFACE	AVERAGE WEIGHT TOTAL DRY MATTER ABOVE SURFACE	WEIGHT OF ROOTS	AVERAGE WEIGHT OF ROOTS	WEIGHT TOTAL DRY MATTER	AVERAGE WEIGHT TOTAL DRY MATTER
	per cent	*tons*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
1	0.6	20	31.5	35.75			31.5	35.75	5.8	5.40	37.3	41.15
2	0.6	20	40.0				40.0		5.0		45.0	
3	0.6	40	48.5	46.75			48.5	46.75	8.0	9.00	56.5	55.75
4	0.6	40	45.0				45.0		10.0		55.0	
5	0.6	60	57.0	54.50			57.0	54.50	8.5	8.50	65.5	63.00
6	0.6	60	52.0				52.0		8.5		60.5	
7	0.6	80	52.5	52.10			52.5	52.10	6.0	7.75	58.5	59.85
8	0.6	80	51.7				51.7		9.5		61.2	
9	0.6	100	53.2	53.30			53.2	53.30	10.2	9.85	63.4	63.15
10	0.6	100	53.4				53.4		9.5		62.9	
11	0.6	120	53.4	54.70			53.4	54.70	6.0	6.35	59.4	61.05
12	0.6	120	56.0				56.0		6.7		62.7	
13	0.6	140	50.5	52.75			50.5	52.75	10.0	8.25	60.5	61.00
14	0.6	140	55.0				55.0		6.5		61.5	
15	0.6	160	45.5	44.65			45.5	45.15	7.5	6.65	53.0	51.80
16	0.6	160	44.8				44.8		5.8		50.6	
17	0.6		37.5	39.50			37.5	39.50	4.6	4.25	42.1	43.75
18	0.6		41.5				41.5		3.9		45.4	
19			47.0	42.50			47.0	42.50	6.7	7.97	53.7	50.47
20			40.0				40.0		11.7		51.7	
21			40.50				40.5		5.5		46.0	

seems actually to have been some stimulation to increased yield over the grain yield of the untreated control pots. However, the manure applications, beginning with 60 tons per acre and going up, are clearly very effective in preventing injury by the Na_2SO_4 both as regards straw and grain yields, and probably also distinctly so for the root yields. In general, therefore, we feel justified in concluding from the data in table 6 that 1.2 per cent Na_2SO_4 in the Berkeley clay adobe soil is distinctly injurious to the development of the barley plant and that its injury may be lessened or entirely inhibited by considerable manure applications.

In the third crop, as represented by table 7, we find the most definite and interesting data of the Na_2SO_4 series. They seem to show beyond a peradventure that in that stage of its development the soil is no longer able to mask the toxic effects of the Na_2SO_4 as it appeared to be able to do at least in some measure in the preceding crop. They also show, as regards straw production, that even the smallest manure application employed is effective in overcoming the injurious effects of the Na_2SO_4 as used, that 40 tons of manure per acre is no more effective in that direction than 20 tons, that the

TABLE 6

Na_2SO_4 *series. Second crop*

NUMBER	Na_2SO_4 ADDED TO SOIL	MANURE RATE PER ACRE	WEIGHT OF STRAW	AVERAGE WEIGHT OF STRAW	WEIGHT OF GRAIN	AVERAGE WEIGHT OF GRAIN	WEIGHT TOTAL DRY MATTER ABOVE SURFACE	AVERAGE WEIGHT TOTAL DRY MATTER ABOVE SURFACE	WEIGHT OF ROOTS	AVERAGE WEIGHT OF ROOTS	WEIGHT TOTAL DRY MATTER	AVERAGE WEIGHT TOTAL DRY MATTER
	per cent	*tons*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
1	1.2	20	19.50	16.55	9.50	8.95	29.0	25.50	2.80	2.05	31.80	27.65
2	1.2	20	13.50		8.40		22.0		1.30		23.30	
3	1.2	40	15.75	15.83	11.45	9.87	27.2	25.70	2.40	1.60	29.60	27.30
4	1.2	40	15.92		8.28		24.2		0.80		25.00	
5	1.2	60	24.53	26.19	8.27	10.96	32.8	37.15	1.37	1.86	34.17	39.01
6	1.2	60	27.85		13.65		41.5		2.35		43.85	
7	1.2	80	26.68	25.64	14.82	12.86	41.5	38.50	2.30	2.65	43.80	41.15
8	1.2	80	24.60		10.90		35.5		3.00		38.50	
9	1.2	100	40.25	35.98	7.95	10.62	48.2	46.60	3.65	4.28	51.85	50.88
10	1.2	100	31.70		13.30		45.0		4.90		49.90	
11	1.2	120	58.40	45.80	4.10	5.45	62.5	51.25	4.00	3.09	66.50	54.34
12	1.2	120	33.20		6.80		40.0		2.18		42.18	
13	1.2	140	43.35	49.52	4.65	4.48	48.0	54.00	1.50	1.90	49.50	55.90
14	1.2	140	55.70		4.30		60.0		2.30		62.30	
15	1.2	160	54.40	55.83	4.30	3.52	58.7	59.35	2.90	3.45	61.60	62.80
16	1.2	160	57.25		2.75		60.0		4.00		64.00	
17	1.2		15.45	16.07	8.55	9.33	24.0	25.40	1.35	1.83	25.35	27.23
18	1.2		16.70		10.10		26.8		2.30		29.10	
19			36.50	27.90	3.00	3.70	39.5	31.60	7.70	8.10	47.20	39.70
20			19.30		4.40		23.7		8.50		32.20	

60 and 80 ton applications are twice as effective as either of the first two and that all the higher applications are about twice as effective as the last two, but nearly equal among themselves. In general, the results show similar tendencies for grain production, except that the difference which we have observed to obtain between the untreated pots and those merely treated with Na_2SO_4, as regards straw production, are not apparent as regards grain production. Just as much grain is produced in pots receiving Na_2SO_4 as in those not receiving any. This is very surprising when we remember how markedly the Na_2SO_4 depressed straw production in the same cultures. The root yields,

however, show much the same effects of the Na_2SO_4 treatment that the grain yields do. Though there are some differences between the two, they are not major differences except possibly for the fact that the protection afforded the straw production by the manure applications is much greater than that afforded the root production. This, of course, might have been expected, owing to the direct contact of the roots with the soil solution.

In the fourth crop, the data for which are set forth in table 8, there is undoubted evidence again of the protective effect of the manure in the directions

TABLE 7

Na_2SO_4 *series. Third crop*

NUMBER	Na_2SO_4 ADDED TO SOIL	MANURE RATE PER ACRE	WEIGHT OF STRAW	AVERAGE WEIGHT OF STRAW	WEIGHT OF GRAIN	AVERAGE WEIGHT OF GRAIN	WEIGHT TOTAL DRY MATTER ABOVE SURFACE	AVERAGE WEIGHT TOTAL DRY MATTER ABOVE SURFACE	WEIGHT OF ROOTS	AVERAGE WEIGHT OF ROOTS	WEIGHT TOTAL DRY MATTER	AVERAGE WEIGHT TOTAL DRY MATTER
	per cent	*tons*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
1	1.2	20	6.50	5.85	2.00	2.40	8.50	8.25	0.50	0.48	9.00	8.73
2	1.2	20	5.20		2.80		8.00		0.46		8.46	
3	1.2	40	5.60	6.05	2.20	2.85	7.80	8.90	1.60	1.40	9.40	10.30
4	1.2	40	6.50		3.50		10.00		1.20		11.20	
5	1.2	60	10.40	10.25	4.40	4.75	14.80	15.00	1.72	1.79	16.52	16.79
6	1.2	60	10.10		5.10		15.20		1.85		17.05	
7	1.2	80	12.85	12.90	7.15	6.30	20.00	19.20	2.20	1.47	22.20	20.67
8	1.2	80	12.95		5.45		18.40		0.74		19.14	
9	1.2	100	30.70	24.35	7.70	9.05	38.40	33.40	1.00	0.80	39.40	34.20
10	1.2	100	18.00		10.40		28.40		0.60		29.00	
11	1.2	120	24.80	25.20	8.60	8.50	33.40	33.70	1.62	1.34	35.02	35.04
12	1.2	120	25.60		8.40		34.00		1.06		35.06	
13	1.2	140	14.50	23.95	5.50	6.85	20.00	30.80	1.50	1.35	21.50	32.15
14	1.2	140	33.40		8.20		41.60		1.20		42.80	
15	1.2	160	28.00	29.70	1.00	3.30	29.00	33.00	1.16	1.68	30.16	34.68
16	1.2	160	31.40		5.60		37.00		2.20		39.20	
17	1.2		3.50	3.60	1.90	1.60	5.40	5.20	0.96	0.81	6.36	6.06
18	1.2		3.70		1.30		5.00		0.66		5.66	
19			12.80	11.95	1.20	1.45	14.00	13.40	3.26	2.48	17.26	15.88
20			15.00		1.00		16.00		2.24		18.24	
21			8.05		2.15		10.20		1.95		12.15	

here considered, and this time as regards straw, grain, and root production. The conditions in the greenhouse were probably better in some way during the growth of the fourth than of the third crop. This seems to have been particularly true for the grain and root production, with special reference to the latter. For some unaccountable reason, root development was far superior in the fourth crop to that in the third and even to that in the second crop. In the fourth crop the 20 and 40 ton applications of manure seem to have lost some of their protective effects, for the yields of straw obtained from

cultures in which they were employed were not even as good as those of the control untreated pots. The duplicate cultures show remarkably good agreement throughout the fourth crop, but it is puzzling to attempt to account for the excellent grain yields which were obtained and especially those of some of the cultures.

It is interesting to note in general throughout the Na_2SO_4 series, what we have already observed in the NaCl series, the tendency for the protective effect of the manure to "wear off" as season follows season. This is well

TABLE 8

Na_2SO_4 *series. Fourth crop*

NUMBER	Na_2SO_4 ADDED TO SOIL	MANURE RATE PER ACRE	WEIGHT OF STRAW	AVERAGE WEIGHT OF STRAW	WEIGHT OF GRAIN	AVERAGE WEIGHT OF GRAIN	WEIGHT TOTAL DRY MATTER ABOVE SURFACE	AVERAGE WEIGHT TOTAL DRY MATTER ABOVE SURFACE	WEIGHT OF ROOTS	AVERAGE WEIGHT OF ROOTS	WEIGHT TOTAL DRY MATTER	AVERAGE WEIGHT TOTAL DRY MATTER
	per cent	*tons*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm*	*gm.*	*gm.*	*gm.*
1	1.2	20	4.45	4.88	2.65	2.57	7.10	7.45	1.00	1.10	8.10	8.55
2	1.2	20	5.30		2.50		7.80		1.20		9.00	
3	1.2	40	5.90	6.20	3.90	3.70	9.80	9.90	1.40	1.30	11.20	11.20
4	1.2	40	6.50		3.50		10.00		1.20		11.20	
5	1.2	60	9.10	9.25	4.40	4.60	13.50	13.85	2.00	2.00	15.50	15.85
6	1.2	60	9.40		4.80		14.20		2.00		16.20	
7	1.2	80	10.00	9.95	6.30	6.20	16.30	16.15	2.40	2.25	18.70	18.40
8	1.2	80	9.90		6.10		16.00		2.10		18.10	
9	1.2	100	13.50	14.75	7.30	7.90	20.80	22.65	Lost	5.00	20.80	24.90
10	1.2	100	16.00		8.50		24.50		5.00		29.00	
11	1.2	120	13.30	15.25	8.70	10.35	22.00	25.60	3.40	3.20	25.40	28.80
12	1.2	120	17.20		12.00		29.20		3.00		32.20	
13	1.2	140	42.60	43.10	25.40	23.50	68.00	66.60	8.40	9.20	76.40	75.80
14	1.2	140	43.60		21.60		65.20		10.00		75.20	
15	1.2	160	46.40	46.50	20.90	20.65	67.30	67.15	8.00	9.00	75.30	76.15
16	1.2	160	46.60		20.40		67.00		10.00		77.00	
17	1.2		4.25	4.40	2.45	2.35	6.70	6.75	0.90	0.95	7.60	7.70
18	1.2		4.55		2.25		6.80		1.00		7.80	
19			7.30	7.80	2.70	3.73	10.05	11.53	4.50	5.17	14.55	16.70
20			8.90		4.20		13.10		7.00		20.10	
21			7.20		4.30		11.50		4.00		15.50	

exemplified by the longer period of protection afforded by the larger than by the smaller manure applications, and the protective effect seems to increase in direct proportion to the increase in the quantity of manure employed. This statement needs some qualification of course, but a study of the data will make clear to the reader the evident tendency which is called to his attention. The reason for the superior protective effect of the manure to the roots in the fourth to that in the third crop does not seem to us evident at the present time.

Series 3. Na_2CO_3

The experiment with the Na_2CO_3 was conducted in the same four seasons as those with the other salts and parallel with them. Only three crops were obtained in series 3, however, since following the second application of Na_2CO_3 (prior to the second crop) the physical condition of the soil was so badly affected by the salt and its effects and the hydroxyl ion concentration probably was so great that the seed planted for the second crop would not germinate. The results of series 3 are set forth, therefore, in three tables, viz., tables 9, 10, and 11, which give the yields of straw, grain, and roots respectively in the first, third, and fourth crops wherever they were obtained.

TABLE 9

Na_2CO_3 *series. First crop*

NUMBER	Na_2CO_3 ADDED TO SOIL	MANURE RATE PER ACRE	WEIGHT OF STRAW	AVERAGE WEIGHT OF STRAW	WEIGHT OF GRAIN	AVERAGE WEIGHT OF GRAIN	WEIGHT TOTAL DRY MATTER ABOVE SURFACE	AVERAGE WEIGHT TOTAL DRY MATTER ABOVE SURFACE	WEIGHT OF ROOTS	AVERAGE WEIGHT OF ROOTS	WEIGHT TOTAL DRY MATTER	AVERAGE WEIGHT TOTAL DRY MATTER
	per cent	*tons*	*gm.*	*gm.*			*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
1	0.3	20	22.8	22.90			22.8	22.90	1.80	1.80	24.60	23.80
2	0.3	20	23.0				23.0				23.00	
3	0.3	40	30.0	34.40			30.0	34.40	3.50	3.10	33.50	37.50
4	0.3	40	38.8				38.8		2.70		41.50	
5	0.3	60	49.5	41.75			49.5	41.75	5.50	4.75	55.00	46.50
6	0.3	60	34.0				34.0		4.00		38.00	
7	0.3	80	38.2	39.85			38.2	39.85	6.50	5.70	44.70	45.55
8	0.3	80	41.5				41.5		4.90		46.40	
9	0.3	100	42.5	41.70			42.5	41.70	6.20	4.70	48.70	46.40
10	0.3	100	40.9				40.9		3.20		44.10	
11	0.3	120	54.0	45.00			54.0	45.00	5.20	4.60	59.20	49.60
12	0.3	120	36.0				36.0		4.00		40.00	
13	0.3	140	47.8	49.30			47.8	49.30	(11.50)	5.75	53.55	55.05
14	0.3	140	50.8				50.8				56.55	
15	0.3	160	46.6	44.60			46.6	44.60	6.20	6.10	52.80	50.70
16	0.3	160	42.6				42.6		6.00		48.60	
17	0.3		10.0	9.00			10.0	9.00	1.00	1.20	11.00	10.20
18	0.3		8.0				8.0		1.40		9.40	
19			47.0	42.50			47.0	42.50	6.70	7.97	53.70	50.47
20			40.0				40.0		11.70		51.70	
21			40.5				40.5		5.50		46.00	

The data of the first crop in this series are probably the only significant ones, since in spite of the doubling of the amount of salt prior to seeding the second crop, the Na_2CO_3 seemed to have lost its toxicity in the third and fourth crop, at least in so far as straw and grain production are concerned. The root yields are unquestionably injured by the effects of the Na_2CO_3

application even in the third and fourth crops, as shown by comparison of the data for the control untreated pots with those for the Na_2CO_3 treated pots and of both of these with the manure treated pots. In view of the foregoing statements, we may dispose of tables 10 and 11 without further comment. A word more may be necessary, however, with respect to table 9. In the latter, which represents the first crop in which only straw and root yields were obtained, the evidence seems to point unquestionably to the injurious effect of 0.3 per cent Na_2CO_3 on both straw and root production of

TABLE 10

Na_2CO_3 *series. Third crop*

NUMBER	Na_2CO_3 ADDED TO SOIL	MANURE RATE PER ACRE	WEIGHT OF STRAW	AVERAGE WEIGHT OF STRAW	WEIGHT OF GRAIN	AVERAGE WEIGHT OF GRAIN	WEIGHT TOTAL DRY MATTER ABOVE SURFACE	AVERAGE WEIGHT TOTAL DRY MATTER ABOVE SURFACE	WEIGHT OF ROOTS	AVERAGE WEIGHT OF ROOTS	WEIGHT TOTAL DRY MATTER	AVERAGE WEIGHT TOTAL DRY MATTER
	pkr cent	*tons*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
1	0.6	20	19.45	18.58	3.15	3.22	22.60	21.80	0.30	0.33	22.90	22.13
2	0.6	20	17.70		3.30		21.00		0.35		21.35	
3	0.6	40		17.95		6.85		24.80		0.60		25.40
4	0.6	40	17.95		6.85		24.80				25.40	
5	0.6	60	31.20	32.80	1.00	2.80	32.20	35.60	0.67	0.74	32.87	36.34
6	0.6	60	34.40		4.60		39.00		0.80		39.80	
7	0.6	80	47.00	42.25	0.40	1.95	47.40	44.20	1.60	1.30	49.00	45.50
8	0.6	80	37.50		3.50		41.00		1.00		42.00	
9	0.6	100	29.95	41.07	3.65	3.53	33.60	44.60	2.00	1.59	35.60	46.19
10	0.6	100	52.20		3.40		55.60		1.18		56.78	
11	0.6	120	32.50	34.80	2.50	2.00	35.00	36.80	1.02	1.02	36.02	37.82
12	0.6	120	37.10		1.50		38.60		1.02		39.62	
13	0.6	140	33.54	43.37	2.86	1.83	36.40	45.20	1.46	1.77	37.86	46.97
14	0.6	140	53.20		0.80		54.00		2.08		56.08	
15	0.6	160	32.00	32.60	4.00	3.90	36.00	36.50	1.70	1.75	37.70	38.25
16	0.6	160	33.20		3.80		37.00		1.80		38.80	
17	0.6		15.40	14.00	4.60	3.00	20.00	17.00	0.57	0.57	20.00	17.57
18	0.6		12.60		1.40		14.00		Lost		14.00	
19			15.00	11.95	1.00	1.45	16.00	13.40	2.24	2.48	18.24	15.88
20			12.80		1.20		14.00		3.26		17.26	
21			8.05		2.15		10.20		1.95		12.15	

barley on that soil. The yield of straw on the Na_2CO_3 treated pots was only about one-fifth as great as on the untreated control pots, and the yield of roots only about one-seventh as great in the same pots. The evidence is also clear in that table that manure exerts a strikingly protective effect on the barley plant as regards both straw and root production. Even the 20 ton manure application is markedly effective so far as straw production is concerned, and with the 60 ton application the yields are practically as good as in the pots receiving no alkali. The other features of table 9 and of the Na_2CO_3 series, in general, speak for themselves.

TABLE 11

Na_2CO_3 *series. Fourth crop*

NUMBER	Na_2CO_3 ADDED TO SOIL	MANURE RATE PER ACRE	WEIGHT OF STRAW	AVERAGE WEIGHT OF STRAW	WEIGHT OF GRAIN	AVERAGE WEIGHT OF GRAIN	WEIGHT TOTAL DRY MATTER ABOVE SURFACE	AVERAGE WEIGHT TOTAL DRY MATTER ABOVE SURFACE	WEIGHT OF ROOTS	AVERAGE WEIGHT OF ROOTS	WEIGHT TOTAL DRY MATTER	AVERAGE WEIGHT OF TOTAL DRY MATTER
	per cent	*tons*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
1	0.6	20	7.20	7.90	3.70	3.80	10.90	11.70	1.00	1.20	11.90	12.90
2	0.6	20	8.60		3.90		10.50		1.40		13.90	
3	0.6	40		8.30		3.50		11.80		0.60		12.40
4	0.6	40	8.30		3.50		11.80		0.60		12.40	
5	0.6	60	24.50	24.55	8.00	7.70	32.50	32.25	1.40	1.45	33.90	33.70
6	0.6	60	24.60		7.40		32.00		1.50		33.50	
7	0.6	80	47.40	29.40	14.10	10.35	61.50	39.75	1.00	0.75	62.50	40.50
8*	0.6	80	11.40		6.60		18.00		0.50		18.50	
9	0.6	100	38.00	30.90	12.00	11.85	50.00	32.75	1.20	2.50	51.20	45.25
10	0.6	100	23.80		11.70		35.50		3.80		39.30	
11	0.6	120	15.60	24.75	10.20	7.50	25.80	32.25	1.50	1.40	27.30	33.65
12	0.6	120	33.90		4.80		38.70		1.30		40.00	
13	0.6	140	31.20	34.65	15.60	12.25	46.80	46.90	4.00	3.75	50.80	50.65
14	0.6	140	38.10		8.90		47.00		3.50		50.50	
15	0.6	160	50.80	55.50	19.50	15.08	70.30	70.55	3.70	4.85	74.00	75.40
16	0.6	160	60.20		10.60		70.80		6.00		76.80	
17	0.6		7.40	6.20	3.40	3.45	10.80	9.65	0.30	0.40	11.10	10.05
18	0.6		5.00		3.50		8.50		0.50		9.00	
19			7.30	7.80	2.70	3.73	10.00	11.53	4.50	5.17	14.50	16.70
20			8.90		4.20		13.10		7.00		20.10	
21			7.20		4.30		11.50		4.00		15.50	

*Spoiled by rain.

GENERAL DISCUSSION

The data presented in the tables and the comments made on them in the discussion having been studied it becomes pertinent to inquire into some of the general bearings of the investigation and its significance, as well as into the nature of the causes which may have contributed to the results obtained. It is interesting first to note how great a tolerance or partial tolerance the barley plant exhibits in the clay adobe soil for the common alkali salts which are used singly. It is important to specify that this is true for this clay adobe soil, since, as many earlier publications have shown, soils vary considerably with regard to their powers to render innocuous more or less of the alkali salts to plants. We speak of this here because this fact has a significant bearing on the theoretical side of our investigation. Soils with a large internal surface always have shown themselves superior to those with a relatively small internal surface in their powers to inhibit the injurious effects of salts on plant growth. The considerable, even striking, resistance of the barley plant to the effects of single alkali salts which we have noted above are

therefore, in all probability, to be ascribed in very large measure to the physical nature of the soil used.

But, as we have shown, even such considerable tolerance of the barley plant to toxic effects of salts is very much enhanced by the addition of organic matter in the form of barnyard manure. It is well known that the rapid decay which manure undergoes in most soils is accompanied by the production of very large quantities of organic colloids. The latter must, of course, increase in very large degree the total internal soil surface. Hence, it is natural to conclude that much, if not all, of the protective effect afforded plants by the incorporation of manure into the soil in which they are grown and which contains alkali is due to the increase of surface in the soil following upon not only the decay of the manure but to some extent also on the mere introduction of the manure into the soil.

The probable mechanism of the action of internal soil surface in inhibiting the toxic effects of salts on plants has been discussed in other papers issued from this laboratory, but may be briefly discussed here again. From long study and on theoretical grounds, we have arrived at the conclusion that the internal surface of soils exerts the effects in question largely by removing from active participation in the actually available soil solution a certain amount of the salt through adsorption—a physical phenomenon well recognized but not clearly understood. The increase in soil surface, therefore, resulting from the addition of organic colloids (in this case from the decay of manure) virtually removes from the sphere of usable soil solution a more or less considerable part of the salt which the normal soil surface, prior to the introduction of the additional colloids, had not removed therefrom. We believe this to be the most important phase of the protective effect of manure in soils containing much soluble salt. Nevertheless, we do not deny that other agencies brought into play by the decomposition of the manure may exert important influences in the same general direction. The chemical reactions occurring between the soluble constituents of the manure and the salt, the changes following therefrom which result in the different balancing of the nutrient and non-nutrient elements of the soil solution, the stimulating effect of constituents of the manure on the plant directly, and indirectly through similar effects on the soil bacteria and solvent effects on the soil minerals, are all doubtless, among other factors, of considerable significance to our problem in the very complicated medium resulting from the mixture of the soil and manure.

Turning now from the theoretical to the practical phases of the question studied in this paper, we should like to direct attention to the following. With all the defects and inaccuracies of such an investigation as that which we have carried out taken into consideration, and with the inherent difficulties which characterize soil and plant problems recognized, there seems still to remain, from a study of our data, the conclusion that manure may be used, if available in sufficient quantity, to render more or less harmless, to plants,

injurious alkali salts in soils. The degree to which manure will thus act depends on the amount of internal surface already possessed by the soil and the amount added by the manure. It is further contingent upon the nature and amount of the manure and the chemical nature of the salts of the soil. It appears now that nothing short of heavy applications of manure to soil will be effective. This may mean applications varying from 10 to 40 tons per acre, depending on the kind of soil and salt and the amounts of the latter present. The protective action of the manure is not permanent but ephemeral, the length of time for which it is effective varying with the amount used and probably with the other factors considered above. It remains true, nevertheless, that on much of the alkali land of the arid west, which contains less salts than the amounts used in our experiments, it should be feasible and profitable to offset the inhibiting effects of the salts on crop growth partly or wholly by the use of barnyard manure, or stable manure and possibly by other forms of organic matter. In connection with this statement, it should be observed that on similar grounds green manure crops, straw, hay, or any form of non-toxic organic matter which will decay with some degree of facility will serve as substitutes for manure and will be as effective as other conditions, which are above discussed, will permit. Our experiments do not furnish any evidence on the effect of manure on mixtures of salts in soils, but previous experiments by the senior author and L. T. Sharp in pot work (1) and in the field (2) have in general given similar results to those above discussed. Needless to say, many more theoretical and practical investigations are needed which will shed further light on this fascinating problem, and they will be forthcoming.

SUMMARY AND CONCLUSION

The authors have conducted an experiment in the greenhouse in pot cultures to determine how manure applications affect soil containing soluble salts as a medium for barley growth. Four successive crops were grown. The salts were tested out singly at rates of 0.3 per cent each NaCl and Na_2CO_3 and 0.6 per cent Na_2SO_4 based on the dry weight of the soil. Additional quantities of salts were added at the same rate prior to planting the second crop and the last three crops were thus grown in the presence of the larger quantities of salts. No conclusions without some qualification can be drawn. The reader is therefore urged to peruse the discussion above. Nevertheless, our data point to the undoubted protective effect exerted by manure in soil for barley plants grown in the presence of alkali salts. Culture pots containing NaCl and Na_2SO_4 give more definite results than those containing Na_2CO_3. It seems fairly certain that our results point to a practical application of considerable value.

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THE ACTION OF SOME COMMON SOIL AMENDMENTS

By J. E. GREAVES and E. G. CARTER

Utah Agricultural Experiment Station

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That some fertilizers have an indirect effect has long been an acknowledged fact. It is no longer believed that the increase in yield obtained from the use of one ton of barnyard manure is alone due to the addition of the two or three pounds of phosphorus and the ten or twelve pounds each of nitrogen and potassium which it contains; but no small part of the increase is due to the liberation of more plant food. This (139) is brought about by the decaying of organic matter with the formation of various acids which in turn act as solvents on insoluble plant-food already in the soil. The benefits obtained from the use of gypsum and lime are due not only to the neutralizing of acid and supplying of calcium, but it was believed that they act indirectly by liberating potassium. From certain results obtained in various experiments, which will be considered later, it seems as if this may be due in part to the rapid mineralization of the soil nitrogen occurring in the presence of these compounds.

The theory of the liberation of plant-food by the addition of various soluble salts to the soil is not a new one, for some writers speak of it as an established fact. This was understood in a general way by Justus von Liebig, as early as 1856, for in his article (65), "Some Points in Agricultural Chemistry," he says: "These salts (speaking of the ammonium salts) contain an acid which exerts an action on the constituents of the soil, an action which is not exerted by pure ammonia. The acids of the ammoniacal salts render the earthy phosphates more soluble in water than they would otherwise be."

A. Stood (137), in a study of the effects of salt water on the soil, attributes part of the bad effects of salt water on land to the rendering soluble of the phosphates which are subsequently washed beyond the plant roots.

For some time in England the agricultural investigators were divided into two schools. One of these claimed that a great increase in yield could be obtained by the use of an insoluble phosphate, while the other claimed that very little—if any—increase in yield could be obtained by its use. Each supported his claim by actual field tests. This difference in results was explained by E. Wildt (162) as being due to the salt which in some cases had been used in connection with the phosphate. Some salts, he claims, when used in connection with a phosphate tend to render it more soluble. Especially does he attribute this property to the various nitrates.

Coming down to the present time we have the statements of Hilgard (46) that lower percentages of potassium, phosphorus, and nitrogen are adequate,

when a large proportion of lime carbonate is present. He states further that a high percentage of lime carbonate may offset a small percentage of phosphorus, apparently by bringing about greater availability. Again, in summing up the chemical actions of carbonates he states that carbonates liberate phosphorus and potassium from insoluble forms.

Wagner (156) found that some of the benefits which result from the use of sodium nitrate are due to its rendering more soluble certain phosphates.

SALTS CONTAINING NITROGEN COMPARED WITH DRIED BLOOD AS A SOURCE OF NITROGEN

As a source of nitrogen the nitrate of soda is usually considered to produce a much better yield than an equivalent amount in the form of dried blood. This is well illustrated in a series of pot experiments by Voorhees (154). The experiments were carried out in the years 1901 and 1902. Sodium nitrate and dried blood were the sources of nitrogen, equivalent amounts of nitrogen being used in each case. As an average of two years and of three experiments each year, dried blood gave a yield of 106.8 gm., while sodium nitrate yielded 110.4 gm. of dry plant.

Patterson (94) obtained similar results with field tests as the following table will show. Each result is the average of two years' work.

TABLE 1

Yield of grain and hay with various nitrogenous fertilizers

CROP	FERTILIZER	GRAIN	FODDER
		bushels	*pounds*
Corn	Sodium nitrate	61.5	3050
Corn	Ammonium sulfate	52.7	2625
Corn	Dried blood	49.7	2812
Wheat	Sodium nitrate	14.9	2030
Wheat	Ammonium sulfate	14.3	1830
Wheat	Dried blood	9.0	884
Hay	Sodium nitrate		4150
Hay	Ammonium sulfate		1900
Hay	Dried blood		2550

The above table shows that corn with sodium nitrate yielded 11.8 bushels and with ammonium sulfate 3 bushels more than it did with an equivalent amount of nitrogen in the form of dried blood. Wheat with sodium nitrate yielded 5.9 bushels and with ammonium sulfate 5.3 bushels more than with the dried blood. Hay produced 1600 pounds more with sodium nitrate and 654 pounds less with the ammonium sulfate than with the dried blood.

A. Müntz (87) also showed that sodium nitrate produced better yields than an equivalent amount of nitrogen in the form of dried blood.

Therefore, under ordinary conditions sodium nitrate is more effective than ammonium sulfate, which, however, is more effective than an equivalent amount of dried blood. This, however, in the case of sodium nitrate and ammonium sulfate is reversed under certain conditions, as will be shown in the following discussion.

The relative value of sodium nitrate and ammonium sulfate when used in connection with an insoluble phosphate

It seems likely that this difference in value of the two fertilizers may be due in part to some indirect effect of the salt. This is at least indicated by the difference in action of ammonium salts and sodium nitrate when used in connection with insoluble phosphate. On ordinary soil sodium nitrate is usually conceded to give the better yield (140). However, when an insoluble phosphate is used in connection with the nitrogenous manure the ammonium salt gives a larger yield than the sodium nitrate or nitrogen from organic sources. Besides, plants grown with the ammonium salts contain a larger percentage of phosphorus.

A great number of experiments have been carried out to ascertain the relative value of insoluble phosphates. A few of them are as follows: Jameson (48) conducted a series of experiments with turnips in which a soluble and insoluble phosphate was used. In one series a soluble salt was used with the phosphates, in the other phosphates were used alone. As an average of forty experiments he obtained with the soluble phosphate 15,133 kilos per acre, while with the insoluble phosphate he obtained 14,663 kilos per acre. This is a difference of 470 kilos in favor of the soluble phosphate. When the same phosphates were used in connection with ammonium sulfate in a series of 12 experiments, the yield was as great with the insoluble as with the soluble phosphate. Now, when the same two phosphates were used in connection with sodium nitrate the soluble gave a yield of 22,240 kilos, while the insoluble gave but 20,525 kilos. It may be seen that there was 1715 kilos per acre in favor of the soluble phosphate. When the above facts are taken into consideration, remembering that nitrates are usually the best form of nitrogen, it would seem that the ammonium sulfate had some effect on the insoluble phosphate.

Krocker and Grahl (59) obtained as large a yield with insoluble phosphate as with soluble phosphates when ammonium sulfate was used in connection with the phosphate.

A number of experimenters have noted the above facts and carried out various experiments to ascertain the nature of this effect. One of the prominent workers in this field is Soderbaum (130), from whose work the following table was taken. The crop grown was oats.

The yield with the bone meal and ammonium sulfate was as great as with the soluble phosphate and sodium nitrate. While not so good as ammonium sulfate, ammonium nitrate gives a better yield than sodium nitrate or the or-

ganic manures. It may be seen that when used with slightly soluble phosphate sodium nitrate is no better than the organic manure.

Thes results have been fully confirmed by more recent experiments by the same worker (130–132) and others, (17, 119).

This greater yield with the ammonium salts has been attributed to a "physiological action" of the ammonium sulfate on the plant, and not to a solvent action on the insoluble plant food. Nedokuchaev (88) found that ammonium sulfate invariably increased the yield over that obtained with other sources of nitrogen, and he considered it due to the sulfate rendering the phosphorus, more soluble and the experiment of Schulov (115) indicates this to be the cause. In these experiments there were two sets of pots, one set in which the ammonium salts and the phosphate were thoroughly mixed, while in the other set the ammonium salts and phosphate were separate but both were accessible to the plant. Where the fertilizers were mixed there was much larger yield obtained with the ammonium nitrate than with the sodium nitrate. However,

TABLE 2

Yield of grain with various fertilizers

FERTILIZER	YIELD OF GRAIN
	gm.
Soluble phosphate	16.1
Soluble phosphate + sodium nitrate	61.9
Bone meal + sodium nitrate	49.4
Bone meal + ammonium nitrate	57.9
Bone meal + ammonium sulfate + sodium nitrate	55.9
Bone meal + ammonium sulfate	62.9
Bone meal + urea	53.1
Bone meal + urea + albumin	51.1

where the nitrogen and phosphorus were separate the yield with each fertilizer was the same.

The work of Brooks (7), at the Hatch Experiment Station on the comparative value of potassium chlorid and potassium sulfate, is of interest in this connection. In a 3-year test on potatoes, there was an average of 22.1 bushels more where the sulfate was used than where the chlorid was used.

We must bear in mind that this beneficial effect of the sulfate may be due in part to the plant-food which it supplies in the form of sulfur. That plants require the presence of sulfur to make a healthy growth is well known. Bogranov, Haseloff and Goosel, König and others have found that part of the beneficial effects obtained from the use of a sulfate is due to the sulfur which acts as a plant food. With Brook's experiment, however, there was an increase in the starch in the potato, and Seisl and Gross (120) found that leaves of potatoes which were rich in starch invariably contained more potassium and phosphorus than ones low in this constituent.

That the increase is not due entirely to the action of the sulfur as a plant-food is further shown when we make a study of the phosphorus in the plants which have been grown with various fertilizers. A Swedish investigator, Weihall, (158) found that oats grown with an ammonium salt contained 0.397 per cent of phosphorus, whereas those grown without the ammonium salt contained 0.375 per cent phosphorus. Prianishnikov (105) found that buckwheat grown with insoluble phosphate and sodium nitrate contained 0.105 per cent of phosphorus, while that grown with the same phosphate, in connection with ammonium nitrate, contained 0.253 per cent phosphorus. Barley grown with ammonium nitrate contained 0.10 per cent more phosphorus than that grown with sodium nitrate.

The experiment which illustrates this best is the mixed herbage of permanent grass land by Lawes and Gilbert (62). As an average of eighteen years, the plat which receives no manure had 2.288 per cent phosphorus in the ash of the grass, while that which received ammonium salts had 2.790 per cent. This is 0.502 per cent more phosphorus in the ash of the plants which had received ammonium salts. In addition to this increase there was a greater yield of hay on the manured than on the unmanured, so that the total phosphorus taken up by the plant would be considerably more in the one case than in the other.

Again, take the plat in the Rothamsted experiment (113) with wheat which received ammonium salts, and compare it with the unmanured plat. The plat which received no manure produced as an average of 42 years $12\frac{3}{4}$ bushels of wheat per acre, while the one receiving ammonium salts averaged $19\frac{1}{2}$ bushels per acre. We find that 11.64 pounds of phosphorus were taken up by the crop on the unmanured land, while the one receiving ammonium salts gave as an average 14.5 pounds per acre. From this we see that there were 2.93 pounds per acre more taken up where the ammonium salts had been used. However, in this case the percentage composition is no higher in the manured grain.

That the phosphorus is more soluble on the plats which have been manured with ammonium salts is further shown by a comparison of the drainage water of the two plats. The unmanured plat had as an average 0.275 parts per million of phosphorus in the drainage water. The plat which received ammonium salts had as an average 0.629 parts per million of phosphorus, thus showing that the drainage water from the manured plat is richer in phosphorus than from the unmanured.

The above facts show that of the nitrogen compounds, ammonium nitrate is the most effective in causing the assimilation of phosphorus from insoluble phosphates. The ammonium sulfate stands next, while sodium nitrate has little if any effect. This is well illustrated by the work of Prianishnikov (104) who made some very thorough tests in which he used phosphorite with various nitrogenous salts. The following table gives the results he obtained with oats:

TABLE 3

Yield of oats, and phosphorus in the oats, with various fertilizers

SOURCE OF NITROGEN	PHOSPHORITE						KH_2PO_4
	$NaNO_3$	$\frac{3}{4}$ $NaNO_3$ $\frac{1}{4}$ $(NH_4)_2SO_4$	$\frac{1}{2}$ $NaNO_3$ $\frac{1}{2}$ $(NH_3)_2SO_4$	$\frac{1}{4}$ $NaNO_3$ $\frac{3}{4}$ $(NH_4)_2SO_4$	$(NH_4)_2SO_4$	NH_4NO_3	$NaNO_3$
Yield (gm.).........	6.900	22.000	20.500	19.200	1.600	18.90	19.800
Per cent phosphorus.	0.039	0.131	0.249	0.402	0.637	0.244	0.231
Total phosphorus in plant (mgm.).....	2.707	30.815	50.990	77.000	9.210	46.02	45.750

The yield was as great with the ammonium nitrate and phosphorite as it was with the soluble phosphate and sodium nitrate. The percentage of phosphorus in the two crops was also the same. Similar tests were made using barley, buckwheat, peas, flax, vetch, and in every case where the ammonium nitrate was used with the phosphate the yield was practically as large as it was with the soluble phosphate. The percentage of phosphorus in the plant was also high with ammonium salts. Thinking this may be due to nitrification, he carried on tests in sterile cultures where nitrification did not occur and found that even then the ammonium nitrate increased the assimilability of phosphorus of insoluble phosphates.

He (106–109) did, however, find that when ammonium sulfate was used alone on some soils the plants were injured by the "physiological action" of the acid condition produced in the soil, although they were super-saturated with phosphorus. The injury from this cause was reduced by the application of small quantities (0.25 per cent) of calcium carbonate, and the yield was increased. When the amount of calcium carbonate was increased to more than 1 per cent all of the free sulfuric acid was neutralized and the plant suffered from phosphorus starvation. The ammonium sulfate not only increased the yield but the phosphorus content of the plants. The difference in the quantity of phosphorus of the soil would account for the various results reported by different workers (43, 147), although it might be assumed that the marked physiological alkalinity of calcium nitrate would depress the assimilation of phosphorus. Yet there are experiments (117) in which the solubility of phosphorus has been increased by it. This must be due to the action of the calcium nitrate on the biologic processes going on in the soil.

Sodium chloride as a fertilizer

Sodium chloride, when used as a fertilizer, varies under different conditions. Some experimenters obtained a good yield from its use, others obtain just as good a yield without it. There must be some cause for this difference and it may be due to its indirect effects on other plant-food either direct or indirect through its action on bacteria.

Storp (141), in an article on sodium chloride as a manure, attributes the benefit derived from its use as due to its decomposing insoluble plant-food. If this be the correct theory we can account for yields such as those obtained by Voelcker (153). As an average of five experiments, on land which had been manured with common salt, the yield of mangels was 36,060 pounds. On the adjoining unmanured ground there was but 26,035 pounds, a difference of a little over 10,000 pounds due to the use of common salt. Now, if the land were rich in insoluble plant-food and the choloride were able to liberate it, we could expect a larger yield. On the other hand, if the soil had been poor in unavailable plant-food no good result would have followed its use. Wheeler (157) seems to have established the fact that sodium chloride cannot to any great extent take the place of potassium salts. However, he does think that sodium chloride can liberate phosphorus from insoluble forms as the following will indicate: "It may, however, be stated here that sodium salts seem to liberate phosphorus and potassium so that under certain circumstances they may act as an indirect manure." In another report (161) he shows that the percentage of phosphorus in a plant is increased by the use of a sodium salt. With radishes this was in some cases as much as 0.052 per cent more in the crop from land which had received a full ration of sodium over that which received but a part ration. In the case of turnips there was a difference of 0.121 per cent, of beets 0.035 per cent, of carrots 0.074 per cent, whereas in the case of the chickory the results are practically the same in the crop from the manured and unmanured land. The report contains many more cases in which sodium chloride increased the phosphorus in the plant.

Most clays, clay soils, muck, and some other soils yield acid solutions when extracted with sodium chlorid, and hence would be able to dissolve insoluble phosphates (86). It is significant that the sodium salts when applied to a soil often not only increase the yield but markedly increase the nitogen content of the crop (151). Ewart (25) considers that the stimulating action of a moderate dressing of sodium chloride is due partly to its solvent action on the mineral constituents of the soil. But Schulze (118) considers that common salt solutions do not have a solvent effect on potassium zeolites, and that if an increase in crop is obtained by fertilizing with common salt it cannot be attributed to the indirect effect of the salt in setting free the potash of potassium zeolites in the soil.

It is quite evident from the preceding consideration that common salt often increase the yield of beets, mangels, barley, wheat, and some other crops. Moreover, it is certain that this increase is due in a large measure to the increased available nitrogen and phosphorus of the soil.

Calcium carbonate on the solubility of plant-food

It is usually conceded that a calcareous soil is exceptionally productive and the soil constituents become available more readily than in the absence of cal-

cium carbonate. Yet there are experiments reported in which calcium carbonate exerted a depressing action on the assimilability of phosphorus from aluminum and iron phosphate (108), raw phosphate, bone meal, and tricalcium phosphate (107–109). Some workers (121) have even found that the addition of calcium carbonate to iron phosphate reduced its solubility in acetic acid and its effectiveness as a food for plants grown in pots. There are, however, experimenters who have found calcium carbonate to increase the availability of aluminum and iron phosphates (33) and Simmermacher (126) found that calcium carbonate does not reduce the fertilizing value of even monocalcium phosphate.

Physically, however, even a small amount of lime carbonate by its solubility in the carbonated soil water will act beneficially in causing the flocculation of clay and in the subsequent conservation of the flocculent or tilth condition, by acting as a light cement holding the soil crumbs together when the capillary water has evaporated, thus favoring the penetration of both water and air. This would enhance bacterial activity such as nitrification (8), nitrogen fixation, and sulfofication (11). It also increases in general the rate of decomposition of organic substances in the soil (63). The increased bacterial activity thus occurring would result in the production of large quantities of organic acids which would react with the insoluble plant-food of the soil rendering it soluble. This would account for the more available phosphorus of the soil noted by some workers (30).

Effects of lime on phosphorus

It seems to be a well-established fact that lime will, under certain conditions, liberate phosphorus from the soil. The more recent work on this subject is that of the Rhode Island Experiment Station. Hartwell and Kellogg (42) in speaking of their turnip experiments, with and without lime say:

> The crop of turnip roots from the limed plat which had received finely ground bone was 62 per cent greater than from the corresponding unlimed plat and the per cent of phosphorus in the dry matter of the roots was 0.378 from the limed plat and 0.351 from the unlimed one. Again, the increase in the crop of turnip roots from the limed plat to which slag meal had been added was 34 per cent as compared with the unlimed plat and phosphorus in the dry matter of the roots was 0.324 per cent from the lime plat and 0.309 per cent from the unlimed one. These increases in the percentage of phosphorus in the turnip roots grown upon the limed plats furnish some evidence that more of the phosphorus in the plats was assimilable.

These same authors made a test of the phosphorus in the soil by extracting with and without lime. They found more phosphorus in the solution from the soil which had been treated with lime than that which had not.

In this same line are the experiments of Kellner (55) and his co-workers. They found in the field and laboratory test that phosphorus was liberated by the use of lime.

Again, the work of Sutherst (142) shows that insoluble phosphates of the soil become much more soluble when treated with lime. Especially was this true in the case of the ferric phosphate. The solvent action was not found to take place when calcium carbonate was used.

The work of Wheeler and Adams, in "A Test of Nine Phosphates with Different Plants," is full of illustrations in which lime has been effective in the liberation of phosphorus. They even claim that it may be of value when a soluble phosphate is used, as may be seen from the following:

The results seem to indicate that in a soil deficient or devoid of carbonate of lime and well supplied with the oxides of iron and aluminum, liming may extend the period of efficiency of the soluble phosphates possible by combining with much of the phosphorus at once, and thus holding it in more assimilable combinations than if it were possible for it all to unite immediately with the iron and aluminum oxides.

Lime may increase the solubility of phosphorus in the soil by replacing iron and aluminum, which is in combination with the phosphorus. It does not, however, increase the soluble potassium of the soil according to Garther (32). Vincent (149) points out that while granite soils are generally supposed to be poor in phosphorus since they respond to applications of phosphorus, the application of lime or chalk has a similar effect. This he attributes to the existence of the phosphorus in unavailable organic combinations with humus which must be neutralized before the phosphorus becomes available.

Calcium sulfate

Calcium sulfate is the most powerful soil stimulant we have. This is due mainly to its liberation of plant-food, especially potassium (72). However, there are soils wherein it does not increase the solubility of the potassium (6) and still there is a response in better crops when gypsum is applied to the soil.

The experiments carried on at Tokyo (50) show that rice yielded better and had a better color when grown on land manured with gypsum.

The analyses made by Boussingault and quoted by Storers (138) shows a greater amount of phosphorus in clover taken from land manured with gypsum. The phosphorus in the clover from the manured land was 10.57 kilos; that from the unmanured 4.80 kilos. The following year, although no more manure was applied, the phosphorus from the hay grown on the manured land was 6.93 kilos more than from the unmanured.

Pfeffer (98) states that Knop found that when seeds are in water containing calcium sulfate, the calcium of the salt is absorbed in a somewhat greater amount than the acid. If this be true it is easy to see how calcium sulfate can assist in the assimilation of phosphorus, even though the phosphates are found to be less soluble in a calcium sulfate solution.

Moreover, the addition of gypsum to a soil often increases the total nitrogen of the crop removed from such a soil (75), and it is well known that gypsum increases very materially the ammonifying, nitrifying, and sulfofying powers of the soil (11).

Iron sulfate

Some writers have made great claims for iron sulfate as a fertilizer. A goodly number of these claims have been made by persons who would profit by its sale. Even when we ignore these cases, there are still cases in which it has produced good results.

The man who made the greatest claim for this, and backed his claim with actual field tests, was Griffiths (40). He made tests with it as a manure on a number of crops. The yields which he obtained were much greater with than without. Especially was this true with beans, turnips mangels, potatoes, meadow hay, and grass. With wheat and other grains the yield did not appear to increase with the application of the iron sulfate. Griffiths attributed this increase in yield to the iron supplied to the plant. For he found considerably more iron in the plants which had been grown on soil manured with iron sulfate than those grown on the unmanured soil. The increase may be due in part to this cause, but a study of the phosphorus of the crop indicates that there is also another cause.

As an average of three years the bean plants grown on land manured with iron sulfate contained 17.95 per cent (40) of phosphorus in the ash, while those grown on adjoining unmanured land contained but 16.47 per cent of phosphorus. In the ash of the pods alone, there was 15.78 per cent phosphoric acid in those from the manured land and 15.03 from the unmanured. The phosphorus in the seed from the manured and unmanured land was the same. With turnip leaves it stood 3.03 per cent in the ash of those grown with the manure and 1.84 per cent in those grown without it. In the roots there was 0.61 per cent more phosphorus in the ash of those grown with sulfate than in those grown without it. Meadow hay had 3.39 per cent phosphorus in the ash of that grown on land manured with the sulfate and 2.34 per cent in that grown without it. Practically the same relationship exists in grass grown under the two conditions. Mangels, 1.00 per cent, potatoes, 1.01 per cent, beet roots, 1.18 per cent more in the ash of those grown on land manured with sulfate than those grown on land not thus manured. Wheat was about the same on manured and unmanured land.

Boetet and Paturel obtained an increase in the crop due to the use of iron sulfate, but they differ from Griffiths in not finding a greater amount of iron in the plants grown on land manured with iron sulfate.

The Hill (150) experiments in England are of the same type. Wheat was grown in pot experiments with and without iron sulfate. The pot which received no sulfate yielded 35.28 gm. of wheat and straw, while an average of the three manured pots was 36.48 gm. The yield was greatest on the pot which received at the rate of 100 pounds of iron sulfate per acre.

Brooks (7) obtained a larger yield of soybeans on land manured with iron sulfate than on unmanured land. However, he did not find a deeper green in the plants on the manured land as did Griffiths.

Lipman (75) found as an average of the results of four years' plat experiments with corn, oats, wheat and timothy, using ferrous sulfate at the rates of 50, 100, and 200 pounds per acre that there was in every an increase in dry matter and total nitrogen of the crop. That the increased nitrogen content of the plant resulted from increased bacterial activity would seem likely from the results reported by Vermarel and Danthony (148) who found that iron pyrites increased the yields of wheat and beans 30 to 60 per cent when used in combination with organic matter. They were without effect when used on soils lacking in organic matter and receiving nitrogen in the form of sodium nitrate.

Other sulfates

The sulfates seem to act very strongly on the insoluble phosphorus of the soil. Where there is a lack of available phosphorus, the sulfates produce yields over and above the chlorids or nitrates with the exception of ammonium nitrate. The Rothamsted experiments illustrate this in a very striking manner. The following table gives the yield of wheat from plats 3, 11, 12, 13, and 14:

TABLE 4

Average yearly yield of wheat for 51 years on the Rothamsted Experimental Farm

PLAT NO.	TREATMENT	AVERAGE 40 YEARS 1852–92	1899	1900	1905
		bu.	*bu.*	*bu.*	*bu.*
3	Unmanured continuously	$12\frac{7}{8}$	12	$12\frac{1}{4}$	18.0
11	400 lbs. ammonium salts, 350 lbs. superphosphates	$24\frac{1}{4}$	$21\frac{1}{4}$	$18\frac{1}{4}$	18.9
12	400 lbs. ammonium salts, 350 lbs. superphosphates, $366\frac{1}{2}$ lbs. sodium sulfate	30	$28\frac{3}{4}$	$24\frac{3}{4}$	30.5
13	400 lbs. ammonium salts, 350 lbs. superphosphates, 200 lbs. potassium sulfate	$31\frac{1}{2}$	$26\frac{3}{4}$	$28\frac{1}{8}$	39.4
14	400 lbs. ammonium salts, 350 lbs. superphosphates, 280 lbs. magnesium sulfate	$30\frac{3}{8}$	$28\frac{1}{4}$	$23\frac{1}{4}$	26.0

It may be seen from table 4 that the plat which received sodium sulfate gave as an average 30 bushels per acre, or $5\frac{1}{2}$ bushels more than plat 11 which, with the exception of the sodium sulfate, was treated the same. This yield is within $1\frac{1}{2}$ bushels of that of plat 13 which received the potassium sulfate. This beneficial effect produced by sodium sulfate is usually attributed to the liberation of potassium. While a considerable part of this beneficial effect is undoubtedly due to this cause, a study of the phosphorus yielded by each plat at least indicates that there is another factor entering. The average yield of phosphorus from plat 11 was 8.27 pounds (62) per acre; while the average on plat 12 was 9.82 pounds per acre. It may thus be seen that as an average of 20 years there were 1.55 pounds more of phosphorus taken from the sulfate plat than from the plat which received no sulfate. When one takes into consideration this excess of 31 pounds of phosphorus which had been removed it would seem that the sulfate

had in some way made the phosphorus more available. As an average of 40 years the plat which received superphosphate alone had 16.46 per cent (34) phosphorus in the ash of the wheat. The plat which received sodium, potassium, and magnesium salts in addition to the superphosphate had 16.78 per cent phosphorus in the ash of the wheat.

The above facts point very strongly to a liberation of phosphorus by various sulfates. This is well shown by the work of Dyer (21). He made a careful study of the soil from the Hoos Field, Rothamsted. The land had been in barley for 42 years. The plat which had received no manure was found to contain 22.27 pounds more phosphorus per acre in the first nine inches than the one which had received ammonium salts. However, the amount soluble in a 1 per cent solution of citric acid was 5.24 pounds more in the latter than in the former. When the plats throughout the entire field were taken the same relationship was found to hold. There was more soluble phosphorus in every case in the plats which had received a sodium, potassium, magnesium, or ammonium salt. If we take Dyer's averages of the plats which were treated nearly alike this fact is brought out even more forcibly than the above. The four plats which received nitrogen but no mineral yielded, as an average of 38 years, $28\frac{1}{2}$ bushels of barley per acre. The soluble phosphorus in these plats was 69 pounds per acre. Now, taking the four plats which received nitrogen, sodium, potassium, and magnesium but no phosphoric acid, they yielded, as an average for the same length of time, $20\frac{1}{2}$ bushels, and contained 103.47 pounds per acre of soluble phosphorus. It may be seen that the latter in the course of 38 years yielded 72 bushels more barley than the former and at the end of this period had 32.61 pounds per acre more soluble phosphorus in the soil. Again, the four plats which received a complete fertilizer had an average yearly yield of $39\frac{3}{8}$ bushels per acre. The plats which received only nitrogen and phosphorus yielded $38\frac{7}{8}$ bushels. At the end of the period there were 549.7 pounds of soluble phosphorus in the one which received a complete fertilizer, while the plat which received nitrogen and phosphorus had only 477.6 pounds of soluble phosphorus per acre in the first 9 inches. This is 72.1 pounds in favor of the plats which received sulfates.

Later Dyer (21a) made a study of the Rothamsted wheat soil, determining the potassium and phosphorus present in a soluble and insoluble condition, and found that pound for pound the magnesium salts are the most effective in keeping the phosphorus soluble. The sodium sulfate comes next and the potassium salts have least effect.

Manganese compounds

Manganese is looked upon as one of the most active catalizers, but the results obtained with it are not always concordant (100, 112).

Some experiments by Skinner and Sullivan (128) demonstrated the fact that manganese acts in various ways as a fertilizer. It is often without influence,

occasionally injurious, but usually beneficial, its effect depending apparently upon the composition and character of the soil. The oxidation in soils under treatment with manganese salts was also studied and it was found that an increase in oxidation and growth frequently occurred in aqueous extracts of poor, unproductive soils; but while oxidation was increased in fertile soils, growth was decreased, the plants showing indications of excessive oxidation. Field experiments showed practically no effect from the manganese salts, but the soil was acid, a condition which may have accounted to a considerable degree for the nature of the results.

It is suggested that when the action of manganese is beneficial.

> It is probably due (a) to the increased oxidation produced in the plant roots whereby the plant is stimulated to greater activity and to increased absorption of the material useful for its growth and general metabolism; (b) *to the stimulation of the activity of microörganisms in the soil*; (*c*) to an increased oxidation within the soil.

The same authors also suggest that when large applications of manganese have been found to be injurious, the injury is undoubtedly due to the "excessive stimulation and excessive oxidation in microörganisms and in the plant, with a resulting charge in the biochemical activities of plant and microörganisms and in the conditions of inorganic and organic soil constituents, the ultimate result of which change is injurious to the growing crop."

An Italian investigator (19) found that manganese carbonate added to the soil with a natural phosphocarbonate greatly increased the yield of wheat and alfalfa, whereas Pfeiffer and Blanck (100) found that manganese caused an increased assimilation of nutritive substances from the soil.

Although the addition of manganese to a soil often increases the nitrogen content of the crop (125) it does not increase the manganese content (44), thus indicating that its action is mainly on the biological transformation of nitrogen and possibly phosphorus which is going on in the soil.

Effect of saline solutions on phosphates

A number of experimenters have done some work in the laboratory to determine the solvent action of various salts in solution on phosphates.

The following is a brief summary of the most important work done on this subject:

Schulov (116) found that a solution of ammonium sulfate extracted more phosphorus from a phosphorite than did the same volume of distilled water. This was found to be true with the nitrate also, but not to as great an extent as with the sulfate solution.

Cameron (14), working with chemically pure iron phosphate, aluminum phosphate, and calcium phosphate, found that the calcium phosphate was slightly more soluble in a solution of potassium chlorid, and less soluble in calcium chloride and calcium nitrate than in distilled water. The iron phos-

phate was more soluble in a potassium sulfate solution and less soluble in a potassium chloride and a sodium nitrate solution than in water. He showed further that equilibrium was not established until at least ten days after the solution had been added to the phosphate.

Kalmann and Bocker (49) extracted soil with a solution of calcium sulfate and with distilled water and obtained the same amount of phosphorus in each case.

Fedler (27) obtained less phosphorus by extracting the soil with sodium nitrate solution than with distilled water. Krouch (60), however, obtained more with a sodium chloride solution than with water. Thompson (143) found the same to hold true when a superphosphate was used in the place of soil.

Both Kellner (55) and Sutherst (142) found that lime rendered the phosphorus of the soil more soluble. Later, Hartwell and Kellogg (42), at the Rhode Island Station, found the same to be true.

Voelcker (152), working with phosphate, bone meal, Cambridge and Suffolk coprolites, found that they were all more soluble in ammonium chloride and in ammonium carbonate solution than in distilled water. Sodium nitrate solution extracted more of the phosphate than did water, while the coprolites yielded the same to each solvent.

Sutherst (142) found that lime extracted more phosphorus from iron and aluminum phosphates than water, but when calcium carbonate was used in place of the lime the same amount of phosphorus was obtained with each solvent. He also found that potassium chloride and sodium chloride solutions each extracted less from bone meal than did distilled water. However, when he used bone flour in place of bone meal, each salt extracted considerably more than the distilled water. He explains this apparent contradiction by assuming that bone meal, when in the soil, undergoes fermentation by which the phosphorus is rendered more soluble, but when quantities of inorganic salts are present this fermentation is prevented.

Liebig (65) showed that sodium nitrate increased the solubility of calcium phosphate, while Lachonicy found that it decreased the solubility of iron phosphate.

Guthrie and Cohen (41) found the amount of water-soluble plant-food larger in limed than in unlimed soil, but only in a sandy soil did liming increase the proportion of water-soluble phosphorus and potassium over that orginally present in the soil. This is due to the calcium of the lime replacing the iron and aluminum which is in combination with the phosphorus of the soil (32). Calcium carbonate may have a similar action on soils rich in aluminum and iron phosphate (33).

König (57), however, found the phosphorus in a soil to be less available the greater the content of lime, magnesia, iron oxid, and clay in the soil.

Foster and Neville (29) found that with increasing quantities of ammonia the quantity of phosphorus passing into solution from various difficultly-soluble phosphates increased at first rapidly and then more slowly, the solubility

of the phosphate being almost directly proportional to the amount of ammonia present. This is similar to the results of Mitscherlich (84) who found the solubility of dicalcium and tricalcium phosphate in water saturated with carbon dioxid was greatly increased by the addition of ammonium sulfate and chloride and chloride and sulfate of sodium and magnesium. Aita (1) found that ammonium, alkali, and magnesium salts brought about an increase in solubility of phosphates proportional to their concentration and dependent upon the factors of friability, fineness, and calcium oxid content. The increase of solubility was a function of the anion.

Patten (93) concluded from his work that a higher concentration of phosphorus may be obtained when weak solutions of salts ordinarily used as soil amendments—potassium chloride, potassium sulfate, potassium and sodium nitrate, or potassium carbonate—are passed through the soil than can be obtained by the use of distilled water.

The senior author (37) tested the solubility of a number of different phosphates in a 1 per cent solution of the various salts with the results reported in table 5.

TABLE 5

Average of phosphorus dissolved by 450 cc. of a 1 per cent solution of each of the following solvents from 2 gm. of each of the phosphates

SOLVENT USED	PHOSPHORUS			
	Weathered phosphate	Unweathered phosphate	White phosphate	Soil and phosphate
	mgm.	*mgm.*	*mgm.*	*mgm.*
Distilled water	0.37	0.23	0.37	0.77
Ammonium nitrate	0.96	0.53	1.16	1.45
Ammonium sulfate	0.60	0.26	0.93	0.82
Sodium sulfate	0.55	0.17	0.82	0.97
Ammonium chloride	0.53	0.35	0.85	0.59
Potassium sulfate	0.51	0.25	0.73	0.95
Magnesium sulfate	0.51	0.28	0.69	0.69
Magnesium nitrate	0.47	0.33	0.70	1.25
Sodium nitrate	0.37	0.20	0.78	0.96
Magnesium chloride	0.37	0.25	0.62	0.68
Potassium chloride	0.35	0.15	0.56	0.43
Potassium nitrate	0.35	0.16	0.65	0.81
Sodium chloride	0.32	0.16	0.39	0.77
Calcium nitrate	0.28	0.22	0.15	0.45
Gypsum	0.20	0.20	0.25	
Calcium sulfate, c.p.	0.18	0.15	0.20	0.40
Calcium chloride	0.13	0.10	0.19	0.42
Iron sulfate	0.14	0.04	0.14	0.30

In every case the iron solution extracted less than the water. This would be expected, for if there were any exchange in the basic ions, there would result iron phosphate which is still less soluble in water than calcium phosphate.

In every case the potassium sulfate, ammonium sulfate, magnesium and ammonium nitrate extracted more phosphorus than did water. Disregarding the result obtained with the soil and phosphate mixed, we find that magnesium sulfate and ammonium chloride rendered the phosphate more soluble. This, however, is reversed on addition of soil to the phosphate. Sodium sulfate, except with the unweathered phosphate, extracted more than water. Comparing the results with sodium and potassium nitrate we find where the brown phosphate was used these solvents depressed the solubility, where the white phosphate (a phosphate containing more calcium and little iron) was used they rendered the phosphate more soluble. This is in accord with the work of other experimenters who have found that these salts depress the solubility of iron phosphate and increase the solubility of calcium phosphate. Sodium, magnesium, and potassium chloride have little if any effect on the phosphate.

Carbon dioxide on soluble plant-food of soil

Under some conditions the large quantities of carbon dioxide liberated from the rapidly decomposing fresh manure may be valuable in rendering soluble plant-food. Bornemann (5) found that soil constantly supplied with carbon dioxide through a pipe buried in the ground gave an increase in yield of 12.2 per cent over the crop grown on untreated soil. Wollny (164) has shown that manure greatly increases the carbon-dioxide production in a soil, and Truog (146) found that the addition of manure to a soil greatly increased the carbon-dioxide produced and for a short time measurably increased the solvent action on floats.

The quantity of carbon dioxide produced in a good aerable soil in 24 hours is enormous. Stoklasa (136) estimated from various determinations that there may be as much as 66.75 pounds per acre to a depth of 15.76 inches produced per day. The bacterial activity of a soil is measured by the amount of carbon dioxide formed in a soil in unit time and this varies widely with the physical and chemical conditions of the soil. Any factor which increases bacterial activity also increases the carbon dioxide generated.

Patten and Brown (92) decided that the carbon dioxide liberated by bacteria played an important part in the dissolving of phosphorus from difficultly soluble phosphates. Pfeiffer and Blanck (99) noted that the keeping of soil charged with carbon dioxide increased the assimilation of phosphorus from such a soil by plants. Although carbon dioxide increases the assimilation of phosphorus the quantity was often greater than could be accounted for by the solvent action of the carbon dioxide, thus indicating other factors at work (102). Herke (45) found sodium nitrate and potassium sulfate to increase the carbon dioxide generated in a soil.

Peterson (97) and Wollny (165) found that lime increased the carbon dioxide given off from soils, and Ebermeyer (22), Hilgard (46) and Hartwell and Kellogg (42) proved conclusively that lime increases the decay taking place in a soil.

Stimulation of bacteria by salts

Withers and Fraps (163) found that calcium carbonate added to a soil greatly accelerated nitrification and that it is especially desirable that it should be added where ammonium sulfate is being used as a fertilizer. Lipman's work (74) showed that calcium carbonate stimulated nitrification more than did gypsum, and that sodium chloride was injurious to nitrifying organisms, while ferrous sulfate in amounts from 10 to 100 mgm., per 100 gm., of soil was without effect. Later, he and Brown (77) decided that both ammonification and nitrification were promoted by magnesia lime to a more marked extent than they were by non-magnesia lime. This, however, was to a certain extent dependent upon the treatment and crop growing on the soil. Both ammonification and nitrification were accelerated by sodium nitrate. In a more recent work Lipman, Brown, and Owen (78) found that small applications of calcium carbonate stimulated bacterial activity, but large applications had detrimental effect upon ammonification.

In Owen's experiments (90), magnesium carbonate was more efficient in promoting ammonification and nitrification than was either calcium or potassium carbonate. According to Engberding (24) ammonium sulfate, sodium nitrate, potassium nitrate, and caustic lime all increase the bacterial content of the soil, but decrease its nitrogen-fixing powers. Krüger's work (61) indicated that calcium carbonate was more effective in promoting nitrification than was lime, the reverse being true with regard to the putrefactive bacteria. The formation of ammonia from peptone was especially favored by calcium carbonate. Lyon and Bizzel (81) found that lime favored nitrification, as did also certain nodule-bearing legumes. Fischer (28) concluded that the presence of calcium carbonate in a nutritive solution favored the formation of protein nitrogen, while magnesium carbonate lessened the transformation of ammonia into protein nitrogen. Calcium oxide, however, exerted a much greater influence upon soil bacteria than did calcium carbonate.

Peck (95) studied the influence of a number of salts upon bacterial activity when applied to the soil, with the result that the carbonate, sulfate and phosphate of calcium were found to stimulate ammonification, while sodium nitrate depressed it; both potassium sulfate and calcium carbonate accelerated nitrification in soil. Brown (10), working with a typical Wisconsin drift soil, found that the application of ground lime up to 3 tons per acre increased the number of bacteria in the soil, also the ammonifying, nitrifying, and nitrogen-fixing powers of the soil. The increase was, in every case, nearly proportional to the limestone applied.

At the times the increase noted in ammonification is due to the retention of the volatile ammonia by the carbonate, as is shown by Lemmermann's results (64) where the addition of calcium carbonate to a soil up to 1 per cent reduced the volatilization of ammonia, but calcium oxide had the opposite effect. Both calcium chloride and calcium sulfate reduced the loss of ammonia, but the chlor-

ide was the only salt of magnesium tested which had this effect. Potassium and sodium chlorides, sulfates and carbonates all reduced the absorptive powers of the soil. Paterson (91) studied the influence of a number of substances upon nitrification with the result that caustic lime was found practically to stop all nitrification. Calcium carbonate promoted it, as did also magnesium carbonate; gypsum was less effective, while ferric hydrate had a very favorable effect.

Kelley (52) studied the effect of calcium and magnesium carbonate alone and in combination upon ammonification and nitrification. In his work calcium carbonate only slightly stimulated ammonification of dried blood, but it had a marked stimulating effect upon nitrification. The magnesium carbonate was found to be toxic to both groups of organisms. No antagonism was found to exist between calcium and magnesium. Later, when working with Hawaiian soils, he (53) reports a stimulation for both. The results, however, varied with different soils, and he considers the lime-magnesia ratio of little importance as regards the ammonifying and nitrifying organisms. Allen's conclusion (2) is that large quantities of limestone must be applied to a non-calcareous soil in order to bring its nitrifying powers up to those of natural calcareous soils.

Chester (15, 16) showed that lime increases the number of bacteria in soil, the increase being proportional to the lime applied up to 4,000 pounds per acre. He considered the effect as due to the lime giving to the soil a more favorable reaction for the growth of bacteria and not to its direct action upon the organisms themselves.

These findings were later confirmed by Fabricicus and von Feilitzen (26), Engberding (24), Ehrenberg (23), and Fischer (28).

Lime not only increases the number of organisms in a soil, but it increases the ammonifying powers of the soil, as is seen from the work of Remy (110), Ehrenberg (23), and Voorhees and Lipman (155).

The literature dealing with the influence of lime upon the nitrifying organisms is voluminous. No attempt is made here to refer to all of it, for in most cases the experiments were conducted on soils which were acid and the lime supplied neutralized the acidity of the soil, thus giving the necessary neutral reaction for the action of the nitrifying organisms. Such results give little, if any, idea of the direct stimulating influence of calcium. Furthermore, the work has recently been summarized by Brown (10) who concludes that the application of lime increased nitrate production from ammonium sulfate and dried blood, the gain being almost proportional to the quantity of lime applied. This, in turn, was found to bear a close relationship to the number of organisms developing on synthetic agar.

Severin (122) concludes from his work that gypsum not only prevents the loss of ammonia from manure, but it increases the speed of decomposition from 10 to 20 per cent, while Paterson and Scott (91) state that gypsum slightly increases nitrification in soil as determined by laboratory experiments. Prior to this, Pichard (103) had shown that the sulfates of calcium, potassium, and sodium promote nitrification.

Opposite results are reported by Dezani (18) who found that gypsum in amounts varying from 0.5 to 2 per cent had no appreciable effect on nitrification, while the results obtained by Lipman and others (76) varied and were inconclusive.

According to Lipman (66) calcium chloride in solutions accelerated the action of ammonifiers, and it is interesting to note that in a later work he (67) failed to find antagonism between either calcium and magnesium or calcium and sodium. The chlorides of calcium, magnesium, potassium, and sodium were found to be toxic in the order named. Marked antagonism exists between calcium and potassium, magnesium and sodium, and potassium and sodium. Sea water was found to be a physiologically balanced solution for *Bacillus subtilis*.

According to Paterson and Scott (91) ferric hydrate has a distinctly beneficial effect upon nitrification. In this latter case its action could be due to its serving as a base. According to Lipman and Burgess (71) the ammonifiers are more sensitive to iron sulfate than are the nitrifiers, for while the latter were stimlated by small amounts of iron sulfate, it was toxic to the former in all concentrations tested.

Magnesium compounds usually stimulate bacterial activities to a greater extent than do calcium compounds, as had been noted in some of the literature already cited, but Engberding's results (24) showed that while magnesium sulfate stimulated bacterial activities, it was not as effective in this regard as was ammonium sulfate, sodium nitrate, or potassium sulfate. The work of Makrinov (82) is of interest, as he found pure maganesium carbonate a very suitable substance on which to grow the nitrous organism. Furthermore, magnesium carbonate had a very beneficial effect on the physiological action of the organism. Kellerman and Robinson (51), on the other hand, found that magnesium carbonate when applied to a soil already rich in magnesium carbonate positively inhibited nitrification if the quantity added exceeded 0.25 per cent. We have here an apparent contradiction, but it may be due to the different conditions of the experiments, as one investigator was working with cultures of the organisms while the other was using the soil with its complex flora. Furthermore, it is quite possible that magnesium carbonate may be without effect upon or even accelerate the growth and activity of the nitrosomonas and yet inhibit the nitromons.

Manganese stimulates higher plants and in many cases acts as a positive catalyzer. Skinner and Sullivan (128) conclude from some of their experiments that manganese salts increase the oxidation in some soils. But while Montanan (85) found that manganese carbonate, sulfate, and dioxid greatly stimulated nitrification, he attributed it to either the direct or the indirect furnishing of oxygen to the nitrifying organisms, and not to any catalytic effect of the manganese itself. Beijerinck (4) observes that some soil organisms have the power of oxidizing manganous carbonate. Olaru (89) found that manganese in the proportion of 1 part to 200,000 parts of nutritive media greatly increases

nitrogen fixation, and he considers it quite likely that the increased yield obtained after the application of manganese compounds to a soil is due to its accelerating the action of the nitrogen-fixing organisms of the soil.

Potassium is essential for the nutrition of both the higher and lower forms of plant life. Hence, it is to be expected that when added to a medium poor in potassium it will increase bacterial growth, but like many other true nutrients it may become toxic if present in too large a concentration. As already noted, Engberding (24) states that potassium sulfate caused a slight increase in the bacterial content of a soil. While Peck (95) found it to increase nitrification in soils, Renault (111) claims that slow ammonification and subsequent nitrification is always accompanied by a low percentage of potash. Dumont's (20) experiments showed that potassium carbonate, added to a soil at the rate of from 1 to 2.5 gm. per 1000 gm. of soil, markedly increased nitrification, but that larger applications of the salt progressively diminished the rate of nitrification, while the addition of 8 gm. to 1000 gm. of soil completely checked it. Lumia (80) concluded that potassium chloride and sulfate were nearly as effective in promoting the activity of alcoholic ferments as were phosphates.

Fred and Hart (31) found that both calcium and potassium sulfates increased ammonification in solution, and that the sulfates of potassium, calcium, and magnesium each increased the evolution of carbon dioxide from soil. But from the results obtained with different salts, they conclude that the addition of the potassium ion did not materially increase ammonification in the soil examined.

Lipman (78) and others found that sodium nitrate increased the accumulation of nitrates in a soil. They found, however, a certain periodicity in the accumulation of nitrates which would account for the different results reported by various investigators, and in later investigations they (76) concluded that at times sodium nitrate stimulates ammonification.

C. B. Lipman (68) demonstrated that ammonification is inhibited by sodium chloride, sodium sulfate, and sodium carbonate. The points at which the salts become toxic are: for sodium chloride, between 0.1 per cent and 0.2 per cent; for sodium sulfate, 0.4 per cent; and for sodium carbonate, 2.0 per cent. A stimulating influence was noted in the case of sodium carbonate, but not in the case of the sulfate or of the chloride. The points at which they became toxic to nitrifiers (69) were found to be: for sodium carbonate, 0.025 per cent; for sodium sulfate, 0.35 per cent; and for sodium chloride, less than 0.1 per cent.

All except carbonate acted as a stimulant in lower concentrations. Later Lipman and Sharp (73) found the point at which sodium chloride became toxic to nitrogen-fixing organisms in soil to be from 0.5 to 0.6 per cent; sodium sulfate, at 1.25 per cent; and sodium carbonate, at 0.4 to 0.5 per cent. Sodium chloride was the only one which acted as a stimulant.

A very extensive piece of work by the authors (39) revealed the fact that sodium carbonate, nitrate, and chloride, potassium carbonate and nitrate, calcium carbonate and sulfate, magnesium sulfate and carbonate, iron nitrate

sulfate carbonate and chloride, and all of the salts of manganese stimulated ammonification. Sodium nitrate and chloride, potassium nitrate and chloride, calcium nitrate, chloride and sulfate, magnesium nitrate, chloride and carbonate, iron sulfate, carbonate, and chloride, all of the salts of manganese stimulated nitrification. The extent of the stimulation varied with the specific salt, as may be seen in fig. 1 wherein the untreated soil is taken as 100 per cent.

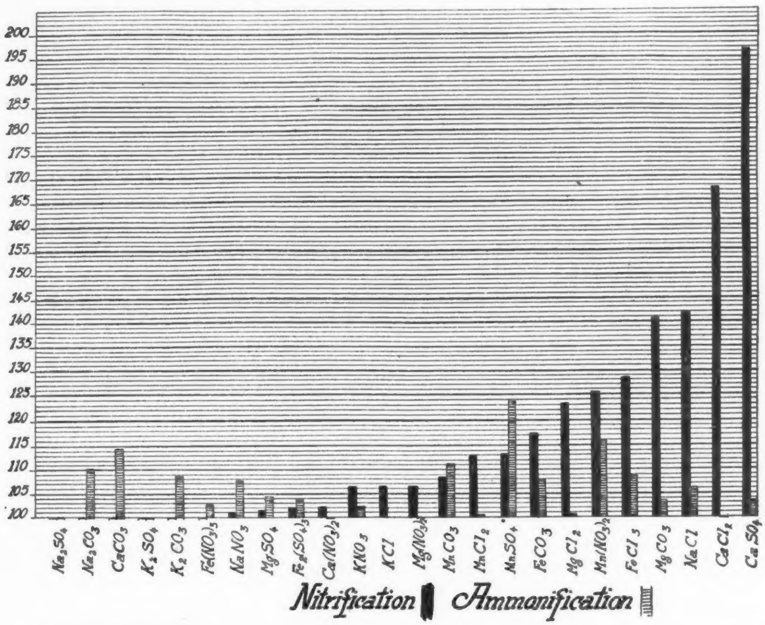

FIG. 1. DIAGRAM SHOWING PER CENT OF AMMONIA AND NITRIC NITROGEN PRODUCED BY BACTERIA IN SOIL RECEIVING VARIOUS SALTS, THE UNTREATED SOIL CONSIDERED AS 100 PER CENT

It is very significant that calcium sulfate, calcium chloride, sodium chloride, and the compounds of iron and manganese, which we have found such marked plant stimulants, are also the most active bacterial stimulants. The results point to the conclusion that the stimulation of the plant is due in no small degree to the increased nitrogen and phosphorus due to the increased bacterial activity of the soil.

Solvent action of bacteria

Brown (9) found that 12 out of the 23 bacteria isolated from soil exerted a definite solvent action on difficultly soluble plant-food. One organism which produced no gas but a large amount of acid showed the greatest solvent action

upon calcium carbonate, while other organisms which produced gas—largely carbon dioxide—but not as much acid as the former gave an action more marked than of the stronger acid-producer upon the dicalcium and tricalcium phosphates. *Bacillus subtilis, Bacillus mycoides, Bacillus proteus vulgaris, and Bacillus coli communis,* as well as several agar cultures from garden soil, were found (114) to be capable of dissolving the phosphates of bone and to a less extent that of mineral phosphates. The greatest solvent action was exerted in media containing sodium chloride, potassium sulfate, and ferrous sulfate. Even yeast (58) may play an important part in dissolving phosphates. But Khober considers that the life activity of the bacteria, that is, assimilation of phosphorus by the living organism, plays little or no direct part in solution of the phosphates, but that the latter is due to the action of the organic acid and of the carbon dioxide produced.

The acids produced by bacteria act upon all kinds of phosphates changing them to the soluble monophosphate, but the rate of solution varies widely with the different phosphates. Tricalcium phosphate, in precipitated form, dicalcium phosphate, and tetracalcium phosphate of Thomas slag are much more rapidly dissolved than the crystalline or the so-called amorphous phosphates. The general reaction is as follows:

$$2\ RCOOH + Ca_3(PO_4)_2 \rightarrow Ca_2H_2(PO_4)_2 + (RCOO)_2Ca$$

The reaction takes place most rapidly in soils containg large quantities of organic matter due to the active fermentation taking place in such soils.

Grazia (36) considers enzyme action to play a part in the dissolving of phosphates in soil, for he found the addition of chlorofrom to a soil reduced bacterial activity and decreased the acid produced, but at the same time the solution of phosphates was increased. This is in keeping with the finding of Bychikhin and Skalski (13).

The presence of ammonium chloride and sulfate in the cultural media is especially effective, according to Perotti (96) in increasing the solvent action of bacteria, for phosphorus. Perotti considers the successive steps in the solution or decomposition of phosphorus in bacteria cultures as follows: (a) generation of acids; (b) secondary reactions in the solution; and (c) production of a soluble phosphorus-containing organic substance. The first two of these are the result of the activity of the bacteria on the phosphorus, and the last is due to the metabolic assimilation of the microörganisms.

The oxidation of sulfur by soil bacteria may at times generate sufficient acid to play a very important rôle in the dissolving of soil phosphorus. However Hopkins and Whiting (47) consider that the nitrite bacteria are of first importance in rendering phosphorus and calcium soluble due to the nitrous acid generated from the ammonia.

$$(NH_4)_2\,CO_3 + 6\,O = 2\,HNO_2 + H_2CO_3 + 2\,H_2O$$

The resulting nitrous acid reacts with the raw rock phosphate rendering it soluble, thus:

$$Ca_3(PO_4)_2 + 4\ HNO_2 = CaH_4(PO_4)_2 + 2Ca(NO_2)_2$$

The actual ratio found showed that about one pound of phosphorus and about two pounds of calcium are made soluble for each pound of nitrogen oxidized aside from the action of the acid radicles associated with the ammonia. The carbonic acid would play an important part also in this reaction:

$$4H_2CO_3 + Ca_3(PO_4)_2 = 2\ Ca(HCO_3)_2 + CaH_4(PO_4)_2$$

They found that neither ammonia-producing bacteria nor nitrate bacteria liberated appreciable quantities of soluble phosphorus from insoluble phosphates.

Whereas this would readily occur in soil poor in calcium carbonate, yet in those rich in calcium carbonate there would be only small quantities of phosphorus liberated, is the conclusion reached by Kelley (53). But where the soluble phosphorus is rapidly being removed by the growing plant there is little doubt but that the various soil organisms play an important part in rendering phosphorus soluble.

Moreover, it is quite evident that *Azotobacter* in their metabolism transform soluble inorganic soil constituents either into soluble or into insoluble organic forms. This is especially true of phosphorus which is found in the ash of these organisms in such large quantities. The phosphorus, on the death of the organism, is returned to the soil in a readily available form, for Stoklasa has found that 50 per cent of the nitrogen of these organisms is nitrified within six weeks, and there is no reason for believing that the phosphorus would be liberated more slowly. Then there is the possibility that many of the constituents of the bacterial cell may become available through the action of autolytic enzymes without the intervention of other bacteria (79).

It is further evident that an organism which possesses the power when growing under appropriate conditions of generating 1.3 times its own body weight of carbon dioxide during 24 hours (135) must greatly change the composition of the media in which it is growing. Water charged with carbon dioxide is a universal solvent and will attack even ordinary quartz rock. Granite and rocks related to it are rather quickly attacked with the liberation of potassium and other elements. Likewise, it would act upon the tricalcium phosphate of the soil with the formation of more readily soluble phosphates, for this substance is four times as soluble in water charged with carbon dioxide as it is in pure water:

$$Ca_3(PO_4)_2 + 2\ CO_2 + 2\ H_2O = Ca_2H_2(PO_4)_2 + Ca(HCO_3)_2$$

Moreover, the nitrogen-fixing organisms form, among other products, formic, acetic, lactic, butyric, and other acids. The kind and quantity of each depends upon the specific organisms and upon the substance on which they are acting. These substances are sure to come in contact with some insoluble

plant-food which may be rendered soluble, for they have a high solvent power for the insoluble phosphates (133). The resulting salts of calcium would be further attacked by bacteria with the formation of calcium carbonate (35).

Whether these processes will give rise to an increase in the water-soluble plant-food of the soil will depend upon whether the products of the second, the analytic reactions, exceed the products of the first, the synthetic reactions. We must not lose sight of the fact that, although many of the organic phosphorus constituents may not be soluble in pure water, they may be more available to the living plant than are the constituents from which they were at first derived through bacterial activity.

This being the case, we may expect to find variations in the results reported from laboratory tests. Stoklasa (134) found that bacterial activity rendered the phosphorus of the soil more soluble, whereas Severin (123) in his early work found the opposite to be true. Others have found that the solvent action of bacteria for insoluble phosphates is in direct proportion to the acid secreted by the organism (114).

In a later work, Severin (124) obtained different results. He used three soils, one sterile, a second sterilized and inoculated with pure cultures of *Azotobacter*, and a third sterilized and inoculated with cultures of *B. radicicola* and *Azotobacter*. The solubility of the phosphorus increased 8 to 14 per cent over that in the sterile soil. The acid-producing organisms, due to the acid secreted and their intimate contact with the soil particles, possess the power of dissolving silicates (3). Moreover, arsenic greatly stimulates nitrogen-fixation and there is a relationship between this increased bacterial activity and the form and quantity of phosphorus found in such a soil (38).

Although the metabolic activity of *Azotobacter* gives rise to large quantities of phosphate solvents, yet these organisms transform phosphorus into organic phosphorus compounds less rapidly than do the ammonifiers (136).

There are, however, cases in which bacterial activity has decreased the water-soluble phosphorus of the soil and of raw rock phosphate (144, 145). But this does not mean that it is less available, for as pointed out by Truog (146) the mixing of floats with manure caused an immediate decrease in the solubility of the phosphorus in 0.2 per cent citic acid solution, yet when thoroughly mixed with the feeding area of the soil its availability was increased to such an extent that some species of plants were apparently able to secure almost an adequate supply of phosphorus from this material. The addition of manure to the soil greatly increased the carbon-dioxid production and for a short time measurably increased the solvent action on floats. Where there is for a time a decrease of water-soluble phosphorus in fermenting media it is probably due to the formation of phosphoproteids within the bodies of the bacteria (127), and these would later be rendered soluble due either to further bacterial activity or autolytic enzymes.

Action of salts and bacteria on phosphorus

We have shown that many salts when applied to a soil increases the accumulation of ammonia and nitric nitrogen in such a soil (39). The magnitude of this stimulation varies with the specific salt and the quantity added. The quantity necessary for maximum stimulation of ammonification and nitrification is given in figure 2, whereas in figure 1 is given the extent of this stimulation.

The question naturally arises as to what effect, if any, this increased stimulation is going to have upon the phosphorus of the soil. We have attempted to answer this question by the following: To tumblers containing 100 gm. of soil and 2 gm., of dried blood were added the fraction of the gram mole which is indicated in the above graph as producing maximum nitrification. These were incubated for 21 days with a moisture content of 20 per cent, and at the end of this time the water-soluble and organic phosphorus were determined.

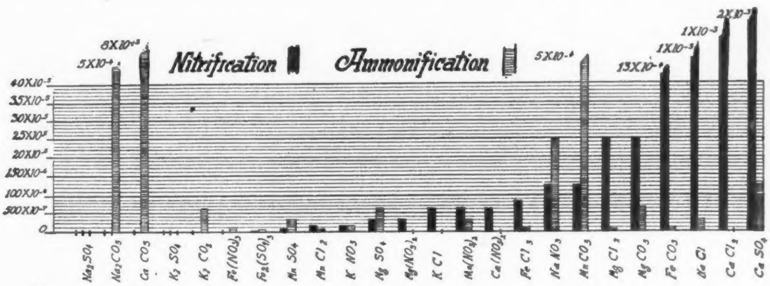

FIG. 2. DIAGRAM SHOWING FRACTION OF MOLECULAR CONCENTRATION OF VARIOUS SALTS IN 100 GRAMS OF SOIL NECESSARY TO PRODUCE MAXIMUM STIMULATION OF AMMONIFICATION AND NITRIFICATION

The water-soluble determinations were made by extracting with water as outlined in a previous article (37). The organic phosphorus determinations were made by the Schmoeger method which consists of extracting ignited and unignited soil with 12 per cent cold hydrochloric acid. In the case of the soil receiving no salt, 12 tumblers of soil were incubated and the phosphorus determinations made on each, and on the salt-treated soil 6 determinations were made. Therefore the results as reported are the average of either 6 or 12 separate determinations with the probable error calculated according to the formula:

$$E = \pm 0.7 \sqrt{\frac{S}{n(n-1)}}$$

S = the sum of the squares of the difference between each result and the average of all the determinations. N = the number of determinations in the average. The results for the sodium salts are given in table 6.

TABLE 6

Water-soluble and organic phosphorus in 100 gm. of soil receiving various sodium salts

TREATMENT	WATER-SOLUBLE PHOSPHORUS	PER CENT PHOSPHORUS	PROBABLE ERROR	ORGANIC PHOSPHORUS	PER CENT ORGANIC PHOSPHORUS	PROBABLE ERROR
	mgm.	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*
None	5.05	100.0	±0.05	6.88	100.0	±0.22
5 x 10^{-4} mol. Na_2CO_3	5.92	117.2	±0.10	6.42	93.3	±0.43
1 x 10^{-3} mol. NaCl	5.52	109.3	±0.12	9.54	138.7	±0.69
125 x 10^{-6} mol. $NaNO_3$	5.10	101.0	±0.08	6.78	98.5	±0.30

All three of the sodium salts increased the water-soluble phosphorus of the soil. This is very marked in the case of sodium carbonate. In this case both the organic and inorganic phosphorus contributed to the water-soluble phosphorus. Sodium chloride when acting in conjunction with bacteria increased the water-soluble phosphorus of the soil 9.3 per cent. This is due to increased bacterial activity and not to direct solvent action of the sodium chloride, for this compound when first applied to a soil fails to increase its water-soluble phosphorus (37). In this case we must conclude that it and 38.7 per cent of the organic phosphorus must come from the more difficultly soluble mineral phosphorus of the soil. These results are a striking confirmation of the theory that the increased yield resulting from the application of sodium chloride to a soil is due in a large measure to its indirect action upon the phosphorus. True, there would also result an increased available supply of nitrogen to the plant, and it is certain that these two factors play a more important part than the direct stimulation of the plant by the sodium chloride. Moreover, it would appear that the active agent is the anion and not the cation.

The results obtained for the potassium salts are given in table 7.

TABLE 7

Water-soluble and organic phosphorus in 100 gm. of soil receiving various potassium salts

TREATMENT	WATER-SOLUBLE PHOSPHORUS	PER CENT PHOSPHORUS	PROBABLE ERROR	ORGANIC PHOSPHORUS	PER CENT ORGANIC PHOSPHORUS	PROBABLE ERROR
	mgm.			*mgm.*		
None	5.05	100.0	±0.05	6.88	100.0	±0.22
156 x 10^{-7} mol. KNO_3	5.46	108.1	±0.09	7.11	103.3	±0.24
625 x 10^{-7} mol. KCl	5.34	105.8	±0.17	7.38	107.3	±0.28
625 x 10^{-7} mol. K_2CO_3	4.71	93.3	±0.16	7.62	110.8	±0.35

Both the chloride and nitrate of potassium increased the water-soluble phosphorus of the soil. This is due to its action upon the soil microörganisms and not to its direct solvent action upon the soil phosphorus, for aqueous solutions of these salts dissolve no more phosphorus from raw rock phosphate or soil than do distilled water (37). Moreover, this increased soluble phosphorus must come from the insoluble phosphates and not from the organic phosphorus of the soil, for these two salts increase the organic phosphorus of the soil 7 and

3 per cent, respectively. The increase in the inorganic phosphorus resulting when potassium carbonate is added to the soil may come mainly from the water-soluble phosphorus, for there is nearly a corresponding decrease in the water-soluble.

The results obtained for the calcium salts are given in table 8.

TABLE 8

Water-soluble and organic phosphorus in 100 gm. of soil receiving various calcium salts

TREATMENT	WATER-SOLUBLE PHOSPHORUS	PER CENT PHOSPHORUS	PROBABLE ERROR	ORGANIC PHOSPHORUS	PER CENT ORGANIC PHOSPHORUS	PROBABLE ERROR
	mgm.			*mgm.*		
None	5.05	100.0	±0.05	6.88	100.0	±0.22
1 x 10^{-3} mol. $CaCl_2$	5.80	114.9	±0.06	6.07	88.2	±0.19
625 x 10^{-7} mol. $Ca(NO_3)_2$	5.77	114.3	±0.25	6.71	97.5	±0.42
8 x 10^{-3} mol. $CaCO_3$	4.25	102.2	±0.08	6.60	95.9	±0.34
2 x 10^{-3} mol. $CaSO_4$	3.71	73.5	±0.07	7.11	103.3	±0.25

Calcium chloride and calcium nitrate are about equally efficient in increasing the water-soluble phosphorus of the soil. But this is due to their action upon the bacteria, for, as would be expected, both of these compounds at first decrease the solubility of soil phosphorus (37). In the case of the calcium chloride the increased water-soluble phosphorus may come from the organic phosphorus of the soil, but in the case of the calcium nitrate it must come mainly from the insoluble mineral phosphates of the soil. Calcium carbonate increases the water-soluble phosphorus of the soil but decreases the organic phosphorus of the soil. This soil in the untreated condition contained over 12 per cent of calcium carbonate, and it may be that a soil poor in calcium carbonate would be stimulated to a much greater extent. Calcium sulfate is the only calcium compound that increases the organic phosphorus, and in this case it is only 3.3 per cent, whereas the decrease in the water-soluble phosphorus amounts to 16.5 per cent. It is therefore quite evident that increased yields resulting from the use of this compound are due mainly to its action upon the available nitrogen of the soil, for it increases the nitric nitrogen content of the soil 95 per cent (39), and only to a very small, if any, degree to the more available phosphorus.

The results obtained for the magnesium salts are given in table 9.

TABLE 9

Water-soluble and organic phosphorus in 100 gm. of soil receiving various magnesium salts

TREATMENT	WATER-SOLUBLE PHOSPHORUS	PER CENT WATER-SOLUBLE PHOSPHORUS	PROBABLE ERROR	ORGANIC PHOSPHORUS	PER CENT ORGANIC PHOSPHORUS	PROBABLE ERROR
	mgm.			*mgm.*		
None	5.05	100.0	±0.05	6.88	100.0	±0.22
312 x 10^{-7} mol. $Mg(NO_3)_2$	5.83	115.5	±0.50	6.54	95.1	±0.34
25 x 10^{-5} mol. $MgCl_2$	5.54	109.7	±0.12	6.64	96.5	±0.19
312 x 10^{-7} mol. $MgSO_4$	5.31	105.2	±0.15	7.68	111.6	±0.53
25 x 10^{-5} mol. $MgCO_3$	4.96	98.2	±0.20	4.97	72.2	±0.06

All of the magnesium compounds except the carbonate increase materially the water-soluble phosphorus of the soil. With the magnesium nitrate and sulfate this may be due largely to the direct solvent action of the salt, for both of these compounds increase directly the solubility of phosphorus (37). But the chloride does not have this same effect. Hence, here it must be due to the action of the salt upon the bacterial flora of the soil. Much of the increased soluble phosphorus must have come from the insoluble mineral phosphates of the soil, for in none of the cases is the decrease in the organic phosphorus sufficient to account for the increase in water-soluble phosphorus. Although the magnesium sulfate increases the water-soluble phosphorus 5.2 per cent, yet the organic phosphorus is increased 11.6 per cent, making this the most efficient phosphorus solvent. This corresponds with its action upon plants and makes it certain that its indirect effect is due mainly to its action upon the insoluble phosphorus of the soil.

Magnesium carbonate had little effect upon the water-soluble phosphorus of the soil, but decreases the organic phosphorus 27.8 per cent. This would make it appear probable that the increased nitric nitrogen of the soil, which in this case amounts to 45.5 per cent over the untreated soil (39), must be due in a large measure to its decreasing the action of bacteria which feed upon nitrates in the soil. Otherwise, if there be an increased bacterial flora we would necessarily have found an increase in the organic phosphorus, for it is inconceivable to think of the organisms functioning without phosphorus in the nucleo-proteins which they must form.

The results for the manganese salts are given in table 10.

TABLE 10

Water-soluble and organic phosphorus in 100 gm. of soil receiving various manganese salts

TREATMENT	WATER-SOLUBLE PHOSPHORUS	PER CENT WATER-SOLUBLE PHOSPHORUS	PROBABLE ERROR	ORGANIC PHOSPHORUS	PER CENT ORGANIC PHOSPHORUS	PROBABLE ERROR
	mgm.			*mgm.*		
None	5.05	100.0	±0.05	6.88	100.0	±0.22
625×10^{-7} mol. $MnCO_3$	5.43	107.5	±0.12	11.19	162.6	±0.35
156×10^{-7} mol. $MnCl_2$	5.06	100.2	±0.07	6.77	98.4	±0.16
78×10^{-7} mol. $MnSo_4$	4.76	94.3	±0.19	7.42	107.9	±0.57
625×10^{-7} mol. $Mn(NO_3)_2$	4.26	84.4	±0.37	6.05	87.8	±0.19

Manganese carbonate is the only one of the manganese compounds which increases the water-soluble phosphorus of the soil. This compound increases the organic phosphorus of the soil 62.6 per cent; hence, this offers a very plausible explanation of why greater yields are obtained when this compound is added to the soil with insoluble phosphate (19). It is not unlikely that much of the benefit resulting from the use of the sulfate is also due to its action upon the soil phosphate. These results, together with the increase in the available nitrogen supply of the soil (fig. 1), are ample to account for the increased yields noted when manganese compounds are applied to the soil.

The results for the iron salts are given in table 11.

TABLE 11

Water-soluble and organic phosphorus in 100 gm. of soil receiving various iron salts

TREATMENT	WATER-SOLUBLE PHOSPHORUS	PER CENT WATER-SOLUBLE PHOSPHORUS	PROBABLE ERROR	ORGANIC PHOSPHORUS	PER CENT ORGANIC PHOSPHORUS	PROBABLE ERROR
	mgm.			*mgm.*		
None	5.05	100.0	±0.05	6.88	100.0	±0.22
104 x 10^{-7} mol. $Fe(NO_3)_3$	6.34	125.6	±0.05	5.58	81.1	±0.42
84 x 10^{-5} mol. $FeCl_3$	5.33	105.6	±0.13	6.52	94.8	±0.24
13 x 10^{-4} mol. $FeCO_3$	5.14	101.8	±0.45	5.72	83.1	±0.55
26 x 10^{-7} mol. $Fe_2(SO_4)_3$	4.76	94.3	±0.37	9.79	142.3	±0.42

Three of the iron salts, the nitrate, chloride, and carbonate, increase the water-soluble phosphorus of the soil. The nitrate increases the solubility 25.6 per cent, but 18.9 per cent of this may have come from the organic phosphorus of the soil, thus leaving the action on the insoluble mineral phosphates small. The increased water-soluble phosphorus resulting where the chloride and carbonate are used is small and may all come from the organic phosphorus of the soil.

Iron sulfate is one of the more powerful soil stimulants, and the field and pot experiments which have been cited indicate that it increases the phosphorus assimilated by the plant. This is not due directly to its solvent action upon the insoluble phosphorus, for at first it greatly decreased its solubility (37). However, these results show it to increase the organic phosphorus of the soil 42.3 per cent, 36.6 per cent of which must have come from the insoluble mineral phosphorus of the soil. It is very probable that this would rapidly become available to the growing plant and this, together with the increased available nitrogen, would be ample to account for the noted gain in crops resulting from its use.

So far in this discussion we have been comparing the action of compounds having the same electro-positive but a varying electro-negative ion. Hence, the results considered have given us an insight into the influence of the anions Cl, SO_4, NO_3, and CO_3 directly and indirectly upon the phosphorus of the soil. It is therefore important that the compounds be compared where the anion is a constant and the cation a variable. This is done for the chloride in table 12.

Probably all of the chlorides increase the water-soluble phosphorus, but only two out of the six increase the organic phosphorus. It is quite evident that both the anion and the cation influence the action of the bacteria upon the phosphorus of the soil, but the influence of the anion probably predominates, for we find all the chlorides increasing the water-soluble phosphorus and all but one of the sulfates decreasing it.

TABLE 12

Water-soluble and organic phosphorus in 100 gm. of soil receiving various chlorids

TREATMENT	WATER-SOLUBLE PHOSPHORUS	PER CENT WATER-SOLUBLE PHOSPHORUS	PROBABLE ERROR	ORGANIC PHOSPHORUS	PER CENT ORGANIC PHOSPHORUS	PROBABLE ERROR
	mgm.			*mgm.*		
None	5.05	100.0	±0.05	6.88	100.0	±0.22
1 x 10^{-3} mol. $CaCl_2$	5.80	114.9	±0.06	6.64	96.5	±0.19
25 x 10^{-5} mol. $MgCl_2$	5.54	109.7	±0.12	6.07	88.2	±0.19
1 x 10^{-3} mol. NaCl	5.52	109.3	±0.12	9.54	138.7	±0.69
625 x 10^{-3} mol. KCl	5.34	105.8	±0.17	7.38	107.3	±0.28
84 x 10^{-5} mol. $FeCl_3$	5.33	105.6	±0.07	6.52	94.8	±0.16
156 x 10^{-7} mol. $MnCl_2$	5.06	100.2	±0.20	6.77	98.4	±0.06

TABLE 13

Water-soluble and organic phosphorus in 100 gm. of soil receiving various sulfates

TREATMENT	WATER-SOLUBLE PHOSPHORUS	PER CENT WATER-SOLUBLE PHOSPHORUS	PROBABLE ERROR	ORGANIC PHOSPHORUS	PER CENT ORGANIC PHOSPHORUS	PROBABLE ERROR
	mgm.			*mgm.*		
None	5.05	100.0	±0.05	6.88	100.0	±0.22
312 x 10^{-7} mol. $MgSO_4$	5.31	105.2	±0.15	7.68	111.6	±0.53
78 x 10^{-7} mol. $MnSO_4$	4.76	94.3	±0.19	7.42	107.9	±0.57
26 x 10^{-7} mol. $Fe_2(SO_4)_3$	4.76	94.3	±0.37	9.79	142.3	±0.42
2 x 10^{-3} mol. $CaSO_4$	3.71	73.5	±0.08	7.11	103.3	±0.34

Every one of the sulfates greatly increases the organic phosphorus of the soil. The "physiological influence" which has been noted by so many experimenters must be due to action of these salts upon the organic phosphorus. Moreover, many experimenters have given to the sulfates first place when used with insoluble phosphates. This would indicate that the organic phosphorus, which is probably largely nucleo-phosphates, becomes available quite readily for plant use.

The results for the carbonates are given in table 14.

TABLE 14

Water-soluble phosphorus and organic phosphorus in 100 gm. of soil receiving various carbonates

TREATMENT	WATER-SOLUBLE PHOSPHORUS	PER CENT WATER-SOLUBLE PHOSPHORUS	PROBABLE ERROR	ORGANIC PHOSPHORUS	PER CENT ORGANIC PHOSPHORUS	PROBABLE ERROR
	mgm.			*mgm.*		
None	5.05	100.0	±0.05	6.88	100.0	±0.22
5 x 10^{-4} mol. Na_2CO_3	5.92	117.3	±0.10	6.42	93.3	±0.41
125 x 10^{-6} mol. $MnCO_3$	5.43	107.5	±0.12	11.19	162.6	±0.35
13 x 10^{-4} mol. $FeCO_3$	5.33	105.6	±0.45	5.72	83.1	±0.55
25 x 10^{-5} mol. $MgCO_3$	4.96	98.2	±0.20	4.97	72.2	±0.06
625 x 10^{-7} mol. K_2CO_3	4.71	93.3	±0.09	7.62	110.8	±0.24
8 x 10^{-3} mol. $CaCO_3$	4.25	102.2	±0.08	6.60	95.9	±0.34

Four of the carbonates increase the water-soluble and three increase the organic phosphorus of the soil. Only one is without effect, the magnesium carbonate. This may be due to the fact that this soil before treatment contains 12 per cent of calcium carbonate and 8 per cent of magnesium carbonate. Therefore it is likely that the phosphorus of a soil low in these constituents would be influenced by the addition of calcium and magnesium carbonate.

The results for the nitrates are given in table 15.

TABLE 15

Water-soluble phosphorus and organic phosphorus in 100 gm. of soil reciving various nitrates

TREATMENT	WATER-SOLUBLE PHOSPHORUS	PER CENT WATER-SOLUBLE PHOSPHORUS	PROBABLE ERROR	ORGANIC PHOSPHORUS	PER CENT ORGANIC PHOSPHORUS	PROBABLE ERROR
	mgm.			*mgm.*		
None	5.05	100.0	±0.05	6.88	100.0	±0.22
104 x 10^{-7} mol. $Fe(NO_3)_3$	6.34	125 6	±0.05	5.58	81.1	±0.42
312 x 10^{-7} mol. $Mg(NO_3)_2$	5.83	115.5	±0.50	6.54	95.1	±0.34
625 x 10^{-7} mol. $Ca(NO_3)_2$	5.77	114.3	±0.24	6.71	97.5	±0.42
156 x 10^{-7} mol. KNO_3	5.46	108.1	±0.09	7.71	103.3	±0.24
125 x 10^{-6} mol. $NaNO_3$	5.10	101.0	±0.08	6.78	98.5	±0.30
625 x 10^{-7} mol. $Mn(NO_3)_2$	4.26	84.4	±0.37	6.05	87.9	±0.19

All but one of the nitrates tested increased the water-soluble phosphorus of the soil and in this regard it is more efficient than is the chloride. Only one potassium nitrate, increases the organic phosphorus. The decrease in organic phosphorus throughout this series may be taken to indicate that the increased water-soluble phosphorus is not due to bacterial activity, but the increase is greater than when the soil or raw rock phosphate is extracted with aqueous solutions of the nitrates. Thus we may consider that the solvent action is due to the nitrous, carbonic, or other acids generated by the bacteria which react with the insoluble mineral phosphates. We must not lose sight of the fact that Perotti (96) suggests—that there are three steps in the solvent action of bacteria, and in the third there is produced a soluble phosphorus containing organic substance and it may be that some of the water-soluble phosphorus is organic in nature.

SUMMARY

The literature cited in the early part of this paper clearly demonstrated that the sulfates of magnesium, calcium and iron, the chlorides of sodium, potassium magnesium and calcium, and the iron and manganese salts are especially efficient as soil stimulants. Furthermore, the evidence was strong that in the case of at least sodium chloride, iron sulfate, and the sulfates of most salts, the action was due to increased available phosphorus, whereas with other compounds it was increased available nitrogen. This theory is corrobated by the results given in table 16.

TABLE 16

Per cent nitric nitrogen water-soluble and organic phosphorus occurring in soil receiving various salts

TREATMENT	NITRIC NITROGEN	WATER-SOLUBLE PHOSPHORUS	ORGANIC PHOSPHORUS
	per cent	*per cent*	*per cent*
None	100.0	100.0	100.0
312 x 10^{-7} mol. $MgSO_4$	101.2	105.2	111.6
26 x 10^{-7} mol. $Fe_2(SO_4)_3$	102.0	94.3	142.3
625 x 10^{-7} mol. $Ca(NO_3)_2$	102.0	114.3	97.5
156 x 10^{-7} mol. KNO_3	106.4	108.1	103.3
625 x 10^{-7} mol. KCl	106.5	105.8	107.3
312 x 10^{-7} mol. $Mg(NO_3)_2$	106.5	115.5	95.1
125 x 10^{-6} mol. $MnCO_3$	108.4	107.5	162.6
156 x 10^{-7} mol. $MnCl_2$	112.9	100.2	98.4
78 x 10^{-7} mol. $MnSO_4$	113.2	94.3	107.9
13 x 10^{-4} mol. $FeCO_3$	117.4	105.6	94.8
25 x 10^{-5} mol. $MgCl_2$	123.2	109.7	96.5
625 x 10^{-7} mol. $Mn(NO_3)_2$	125.4	84.8	87.9
84 x 10^{-5} mol. $FeCl_3$	128.3	105.6	94.8
25 x 10^{-5} mol. $MgCO_3$	140.7	98.2	72.2
1 x 10^{-3} mol. NaCl	142.0	109.3	138.7
1 x 10^{-3} mol. $CaCl_2$	167.2	114.9	88.2
2 x 10^{-3} mol. $CaSO_4$	196.7	73.5	103.3

It is quite evident from these results that the increased available nitrogen and phosphorus is sufficient to account for the noted increase in crop yields resulting from the use of these soil amendments. For the increase in nitric nitrogen varies from 1 to 96.7 per cent, whereas the water-soluble phosphorus is increased in all but five of the seventeen salts listed. This increase varies from 0.2 per cent up to 15.5 per cent. Three of the salts which failed to increase the water-soluble phosphorus increases the organic phosphorus. Hence, the available phosphorus has been increased in all but two of the seventeen salts listed. The increase in organic phosphorus varies from 3.3 per cent with the calcium sulfate to 62.6 per cent with the manganese carbonate. The strong stimulant, sodium chloride, acts to a great extent by rendering phosphorus soluble, whereas the equally strong stimulant, calcium sulfate, acts by rendering available more nitrogen.

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BOTANICAL COMPOSITION OF A PERMANENT PASTURE AS INFLUENCED BY FERTILIZERS OF DIFFERENT COMPOSITIONS

J. J. SKINNER

Soil Fertility Investigations, U. S. Department of Agriculture

AND

C. F. NOLL

Agronomy Department, Pennsylvania Agricultural Experiment Station

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In the experiments under consideration the character of vegetation in a field under permanent pasture containing mixed herbage, as influenced by the fertilizer constituents, phosphate, nitrate, and potash, used singly and in combinations of various ratios, was ascertained. The growth produced each year was recorded and the increase or decrease of each species existing originally in the field was noted from time to time. This fertilizer experiment on grass was started in 1910 at the Pennsylvania Experiment Station at State College, Pennsylvania, the plots being located on a permanent pasture where the composition of the vegetation was chiefly Canada bluegrass, Kentucky bluegrass, and timothy, with relatively smaller amounts of white and red clover. The pasture was used for grazing for several years preceding the first application of fertilizers. Since that time the hay has been cut annually, its botanical composition noted and the total yield recorded. Some marked differences have been noted in the composition of vegetation from the differently fertilized plots.

The soil is of the Hagerstown Series with the surface soil chiefly loam and the sub-soil chiefly clay and silty clay loam. The soil may be described as a grayish brown to brown mellow soil, varying in depths on the plots from about 7 to 11 inches; the sub-soil is a yellowish brown to reddish brown clay to silty clay loam, passing at about 24 inches into a stiff, heavy, yellowish-red clay which extends to a depth of 3 feet or more. The sub-soil contains some disintegrated rock fragments. The material is derived from the weathering of limestone. The topography of the area is rolling, insuring good drainage. The field under experimentation had previously been for 20 to 30 years in a rotation of corn, oats, wheat, each one year, and clover and timothy one year. In 1906–1907 the field was in wheat when it was seeded to timothy in the fall and to clover in the spring. It was pastured in 1908 and in 1909. The practice had been to apply a moderate application of manure once in a rotation, usually on the sod for the corn crop, and acid phosphate for the wheat at the rate of about 200 pounds per acre. The part of the field in which this experiment is located was never limed.

PLAN OF THE EXPERIMENT

The experiment was run in duplicate, using the three principal fertilizer ingredients, acid phosphate, sodium nitrate and potassium chloride, singly, in combinations of two, and in combinations of three, the ratios varying in 10 per cent stages. The scope of the experiment is explained best by the use of the triangular diagram, which has been used extensively in nutrient culture solution experiments, and in fertilizer studies (2). The triangular diagram is shown in colors in plate 1. Each of the 66 circles represents a fertilizer mixture. The red represents acid phosphate, P_2O_5; the black, sodium nitrate, NH_3; and the white, potassium chloride, K_2O. Circle or plot 1 receives acid phosphate alone. Plot 56 potassium chloride alone and plot 66 sodium nitrate alone. The series from 1 to 56 represents mixtures of acid phosphate (red), and potassium chloride (white). Plot 2 has 90 per cent of P_2O_5 and 10 per cent of K_2O. Plot 46 has 10 per cent P_2O_5, and 90 per cent K_2O. Plot 16 has equal amounts of P_2O_5 and K_2O. Likewise the mixtures represented by the series from 56 to 66 are mixtures of potassium chloride (white) and sodium nitrate (black). Plot 61 has equal amounts of NH_3 and K_2O. The series from 1 to 66 represents mixtures of P_2O_5 and NH_3. Plot 21 has equal amounts of P_2O_5 and NH_3. Circles on the base line 56 to 66 represent mixtures containing no P_2O_5. The next tier of circles, namely 46 to 55, represents mixtures containing throughout 10 per cent P_2O_5, but varying amounts of the other two constituents. Similarly the series from 37 to 45 represents throughout 20 per cent mixtures of P_2O_5; series 29–36, 30 per cent mixtures of P_2O_5 and so on upward until 1, the apex of the triangle is reached, where the composition is 100 per cent P_2O_5. Similarly circles on the line 1–66 represent 0 per cent K_2O; series 2–65 represents 10 per cent K_2O, but varying amounts of P_2O_5 and NH_3, and so on until at 56 the composition is 100 per cent K_2O. Likewise, plots on the line 1–56 receive no NH_3, series 3–57 receives 10 per cent NH_3, but varying amounts of P_2O_5 and K_2O, and so on until at 66 the composition is 100 per cent NH_3. Any circle within the triangle represents a mixture composed of the three constituents, its position in the triangle being determined by the composition, namely, the percentage of the three component parts, P_2O_5, NH_3, and K_2O. For instance, circle or plot 12 being on the 60 per cent phosphate line represents that composition of P_2O_5, namely 60 per cent, and being at the same time on the 10 per cent NH_3 line and 30 per cent K_2O line it represents 10 and 30 per cent of these constituents, respectively. The composition of the mixture represented by this circle is therefore P_2O_5 60 per cent, NH_3 10 per cent, and K_2O 30 per cent. The composition represented by each circle is given in table 1. The details of preparing the fertilizer mixtures according to the triangular system are fully explained in the publication cited.

The total amount of fertilizers applied annually was 50 pounds per acre of $P_2O_5 + NH_3 + K_2O$. The plot receiving acid phosphate only, received 50

pounds per acre of the constituent P_2O_5, the one receiving only potassium chloride received 50 pounds per acre of K_2O, and the one receiving sodium nitrate 50 pounds per acre of NH_3. The plots receiving two or three fertilizers, received the sum total of 50 pounds per acre of the constituents, $P_2O_5 + NH_3$, or $P_2O_5 + K_2O$, or $NH_3 + K_2O$, or $P_2O_5 + NH_3 + K_2O$, as the case may be. The fertilizers have been applied each year early in April soon after the grass began to grow.

TABLE 1

Composition represented by each circle in plate 1

PLOT	FERTILIZER ADDED PER ACRE			PLOT	FERTILIZER ADDED PER ACRE			PLOT	FERTILIZER ADDED PER ACRE		
	P_2O_5	NH_3	K_2O		P_2O_5	NH_3	K_2O		P_2O_5	NH_3	K_2O
	pounds	*pounds*	*pounds*		*pounds*	*pounds*	*pounds*		*pounds*	*pounds*	*pounds*
1	50	0	0	23	20	5	25	45	10	40	0
2	45	0	5	24	20	10	20	46	5	0	45
3	45	5	0	25	20	15	15	47	5	5	40
4	40	0	10	26	20	20	10	48	5	10	35
5	40	5	5	27	20	25	5	49	5	15	30
6	40	10	0	28	20	30	0	50	5	20	25
7	35	0	15	29	15	0	35	51	5	25	20
8	35	5	10	30	15	5	30	52	5	30	15
9	35	10	5	31	15	10	25	53	5	35	10
10	35	15	0	32	15	15	20	54	5	40	5
11	30	0	20	33	15	20	15	55	5	45	0
12	30	5	15	34	15	25	10	56	0	0	50
13	30	10	10	35	15	30	5	57	0	5	45
14	30	15	5	36	15	35	0	58	0	10	40
15	30	20	0	37	10	0	40	59	0	15	35
16	25	0	25	38	10	5	35	60	0	20	30
17	25	5	20	39	10	10	30	61	0	25	25
18	25	10	15	40	10	15	25	62	0	30	20
19	25	15	10	41	10	20	20	63	0	35	15
20	25	20	5	42	10	25	15	64	0	40	10
21	25	25	0	43	10	30	10	65	0	45	5
22	20	0	30	44	10	35	5	66	0	50	0

The plots were laid off according to the triangular system as shown in figure 1. They were made 10 feet square and are separated by 2-foot paths. The plots were laid off in duplicate with a 10-foot area separating the two series, or triangles. Besides the 66 treated plots, in each series there are 6 check plots. From their relative positions, the two series in this discussion will always be referred to as the North Triangle and the South Triangle.

The hay was cut each year, early in July, and records made of the yield from each plot. The vegetation was allowed to grow, mature, and seed for the remainder of the season. No second cutting was made.

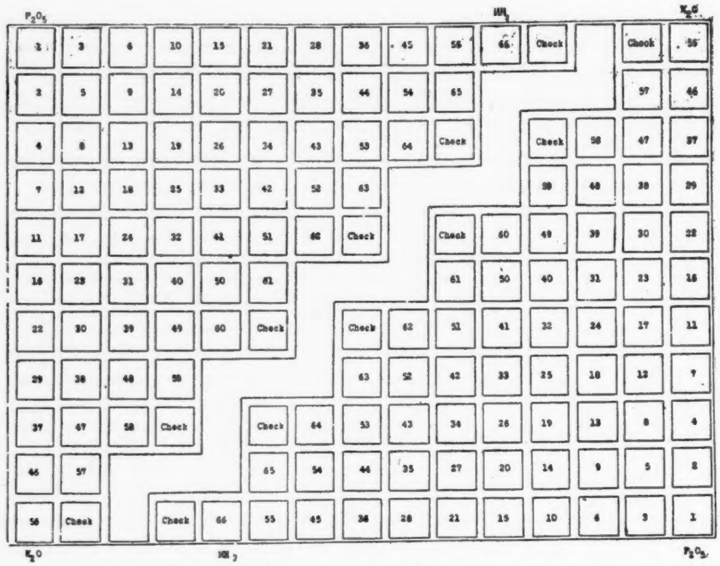

FIG. 1. ARRANGEMENT OF FIELD PLOTS OF THE FERTILIZER RATIO EXPERIMENT WITH GRASS

Plots 10 feet by 10 feet. (1) North Triangle. (2) South Triangle.

INFLUENCE OF FERTILIZERS ON YIELD

The data published in 1914, show that during the first four years of the experiment, the fertilizer mixtures composed principally of nitrate, that is, those plots in the nitrogen end of the triangle, produced the largest yields (1). The yields from these plots were larger than from the plots in the phosphate or potash end of the triangle, and considerably larger than from the untreated plots.

In table 2 is given in pounds per acre the average annual yield of cured hay from each plot of the two experiments for seven years, 1910 to 1916, inclusive.

The average annual yield of the 6 unfertilized plots of the North Triangle was 1136 pounds per acre, and of the 6 untreated plots of the South Triangle 1135 pounds per acre. Practically all of the fertilizer combinations produced larger yields than did the unfertilized soil. The increased yields are especially marked on the plots which received a fertilizer ratio high in nitrogen.

In figures 2 and 3 the relative yields are shown diagrammatically, and a better idea of the effect of the fertilizers can be secured than by a study of the large number of figures in the table. The charts are constructed so that the amount of hay from each plot is in proportion to the area of the circle. In these diagrams the area of the circle is proportional to the numbers given in table 2

and is obtained by finding the radius corresponding to these numbers as areas of a circle, according to the formula: $A = \frac{R^2 \pi}{x}$ for which R can either be calculated or taken from a table of such values to be found in many books. The

TABLE 2

Average annual yield of cured hay per acre for seven years (1910–1916)

PLOT	FERTILIZER ADDED PER ACRE			NORTH TRIANGLE	SOUTH TRIANGLE	PLOT	FERTILIZER ADDED PER ACRE			NORTH TRIANGLE	SOUTH TRIANGLE
	P_2O_5	NH_3	K_2O				P_2O_5	NH_3	K_2O		
	pounds	*pounds*	*pounds*	*pounds*	*pounds*		*pounds*	*pounds*	*pounds*	*pounds*	*pounds*
1	50	0	0	1238	1207	34	15	25	10	1922	1569
2	45	0	5	1226	1152	35	15	30	5	1731	1637
3	45	5	0	1392	1702	36	15	35	0	1770	2377
4	40	0	10	1178	1646	37	10	0	40	1402	1413
5	40	5	5	1672	1613	38	10	5	35	1399	1699
6	40	10	0	1508	1502	39	10	10	30	1728	1612
7	35	0	15	1440	1101	40	10	15	25	1632	1563
8	35	5	10	1627	1561	41	10	20	20	2129	1554
9	35	10	5	1559	1411	42	10	25	15	1997	1482
10	35	15	0	1512	1200	43	10	30	10	2112	1806
11	30	0	20	1539	1233	44	10	35	5	1854	2424
12	30	5	15	1542	1609	45	10	40	0	1942	2602
13	30	10	10	1318	1369	46	5	0	45	1651	1344
14	30	15	5	1580	1507	47	5	5	40	1392	1516
15	30	20	0	1672	1249	48	5	10	35	1299	1560
16	25	0	25	1613	1250	49	5	15	30	1752	1672
17	25	5	20	1473	1498	50	5	20	25	2007	1453
18	25	10	15	1630	1488	51	5	25	20	2140	1536
19	25	15	10	1677	1084	52	5	30	15	2009	1660
20	25	20	5	1940	1479	53	5	35	10	1347	2198
21	25	25	0	1796	1723	54	5	40	5	1854	2373
22	20	0	30	1730	1289	55	5	45	0	1827	1926
23	20	5	25	1733	1421	56	0	0	50	1297	1233
24	20	10	20	1691	1346	57	0	5	45	1488	1420
25	20	15	15	1728	1151	58	0	10	40	1657	1360
26	20	20	10	1996	964	59	0	15	35	1710	1752
27	20	25	5	1957	1804	60	0	20	30	1610	1685
28	20	30	0	1912	1879	61	0	25	25	1834	1440
29	15	0	35	1643	1464	62	0	30	20	1968	1440
30	15	5	30	1407	1236	63	0	35	15	2120	1656
31	15	10	25	1710	1444	64	0	40	10	1910	1782
32	15	15	20	1795	1367	65	0	45	5	1903	2400
33	15	20	15	1651	1138	66	0	50	0	1728	2445

position of the circle indicates the fertilizer composition of the plot as explained in connection with plate 1.

Considering first the North Triangle, the relative yields of which are shown in figure 3, it is seen that the larger circles all occur in the nitrogen end of

the triangle, that is, in that region of the triangle where the fertilizer mixtures contain from 25 to 35 pounds per acre of NH_3, from 5 to 20 pounds of P_2O_5, and from 5 to 15 pounds of K_2O, namely the group of plots marked, 27, 34, 35, 42, 43, 44, 51, 52, 53, 54 (pl. 1). It is very noticeable that the circles which lie further from this group, either in the direction of the phosphate or potash end of the triangle become smaller.

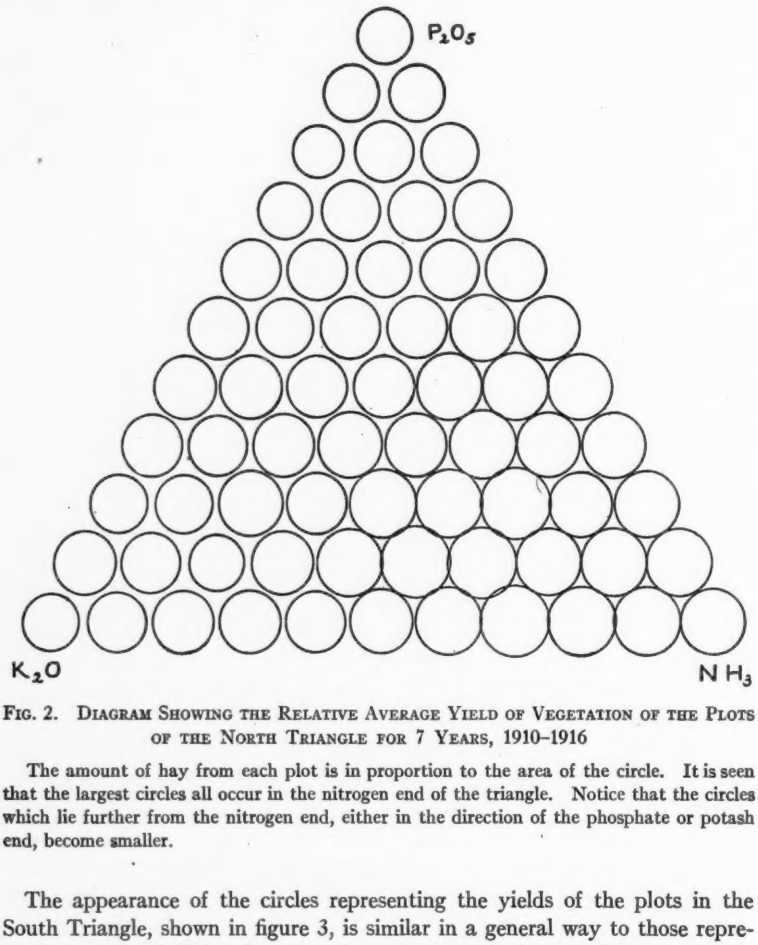

FIG. 2. DIAGRAM SHOWING THE RELATIVE AVERAGE YIELD OF VEGETATION OF THE PLOTS OF THE NORTH TRIANGLE FOR 7 YEARS, 1910–1916

The amount of hay from each plot is in proportion to the area of the circle. It is seen that the largest circles all occur in the nitrogen end of the triangle. Notice that the circles which lie further from the nitrogen end, either in the direction of the phosphate or potash end, become smaller.

The appearance of the circles representing the yields of the plots in the South Triangle, shown in figure 3, is similar in a general way to those representing the North Triangle. Here it is seen that the largest circles are in the extreme nitrogen end of the triangle, and like the circles of figure 2 grow smaller towards the phosphate or potash end. The largest yields in this experiment are in the plots which receive mixtures containing from 35 to 50 pounds per

acre of NH_3, from 5 to 10 pounds of P_2O_5, and from 0 to 10 pounds of K_2O. This group comprises plots 36, 44, 45, 53, 54, 55, 65, and 66.

Thus the two experiments agree in showing that the largest yields are produced by the fertilizer mixtures containing principally nitrogen, with relatively smaller amounts of phosphate and potash.

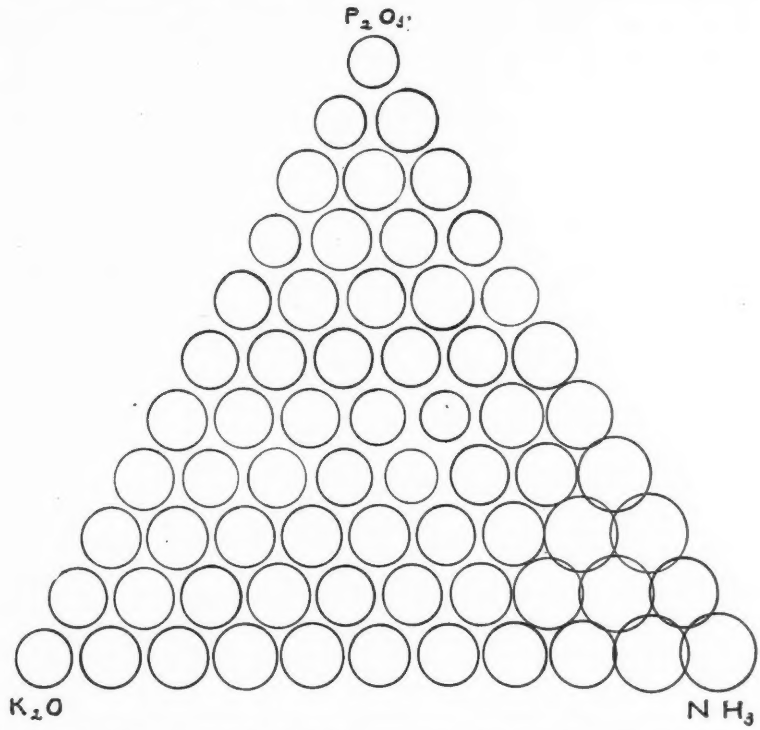

FIG. 3. DIAGRAM SHOWING THE RELATIVE AVERAGE YIELD OF VEGETATION OF THE PLOTS OF THE SOUTH TRIANGLE FOR 7 YEARS, 1910–1916

The amount of hay from each plot is in proportion to the area of the circle. Like the yield in its companion experiment (fig. 2) the largest circles all occur in the nitrogen end of the triangle, becoming smaller as one looks toward either the phosphate or potash section of the diagram.

INFLUENCE OF FERTILIZERS ON THE BOTANICAL COMPOSITION OF THE VEGETATION

The species of grasses which predominate in the differently fertilized plots present some interesting features. It should be recalled that the field was seeded to grass with wheat in 1906, and to clover in the spring of 1907. It

was pastured from 1908 to 1909, when the field was divided into plots and the annual application of fertilizers begun in 1910. At this date the entire area on which the plots are located had a fairly uniform stand of grass, consisting principally of Canada bluegrass (*Poa compressa*), Kentucky bluegrass (*Poa pratensis*), and timothy (*Phleum pratense*), with smaller amounts of white (*Trifolium repens*) and red clover (*Trifolium pratense*). The three grasses prevailed over the entire area in the proportion of about 50, 30, and 20 per cent, respectively. When the individual plots were studied in 1916 it was found that they were quite variable in the species which predominated, there being a relation between the composition of the vegetation and the fertilizer.

The dominance of each species in 1916, is shown graphically in figures 1 and 2, plate 2. The amount of each species had been determined for several years by going upon the plot before the hay was ready to cut and noting carefully the relative amounts of each kind of grass. In 1916 the record included also the percentage of white and red clover. The per cent of each species as found in 1916 is charted in the circles, representing each of the 66 plots. The three shades of green represent the three grasses, timothy, Kentucky bluegrass, and Canada bluegrass, and two shades of red the two clovers, white and red, as shown in the key on the charts.

North Triangle

Grasses. Considering first the composition of the vegetation on the North Triangle as shown in figure 1, it is seen that the Kentucky bluegrass is by far the most dominant of the grasses. This is especially true in the nitrogen end of the triangle. Here the other grasses have almost disappeared. In plot 66 which received only nitrogen fertilizers the grass is all of this species; and in plots 55 and 56, which receive 45 pounds per acre of NH_3, the grass is 95 per cent Kentucky bluegrass. This is also true in the next nitrogen line of plots, that is plots 45, 54 and 64. These plots receive a fertilizer mixture, containing 40 pounds of NH_3 per acre, with 10 pounds of the other constituents alone and together. The next line of nitrogen plots, 36, 44, 53 and 63, which receive a fertilizer mixture, containing 35 pounds per acre of NH_3, and 15 pounds of the other constituents, has in each case 90 per cent Kentucky bluegrass. Proceeding from the nitrogen end of the triangle the grasses, especially Kentucky bluegrass, diminish, giving way to clover. Canada bluegrass has disappeared from all of the plots, except 56 and 57, two plots which receive high potash fertilizers and are low in nitrogen and phosphorus. Small amounts of timothy have persisted in certain of the plots; it is perceptible that only a few plots in the nitrogen end of the triangle contain timothy, its occurrence being more frequent in the plots near the interior and towards the phosphate and potash ends of the triangle.

In 1912, the first year in which detail notes were made, the 21 plots in the nitrogen end of the triangle, that is those plots within the sub-triangle (pl. 1)

bounded by 66, 21 and 61 contained the three grasses, timothy, Kentucky bluegrass and Canada bluegrass in the proportion of 17, 52, and 31 per cent, respectively. In 1916 these 21 plots as a unit contained no Canada bluegrass, about 5 per cent of timothy, and approximately 77 per cent of the entire vegetation was Kentucky bluegrass. The average composition of the vegetation of these 21 nitrogen plots is shown in the small separate circle of figure 1, plate 2, marked 69.

In 1912 the relative amounts of the three grasses in the 21 mainly phosphate plots, those in sub-triangle, marked by plots 1, 16 and 21 was 14 per cent timothy, 25 per cent Kentucky bluegrass, and 61 per cent Canada bluegrass. As shown in circle 67, which gives the average composition of these 21 plots the Canada bluegrass has disappeared from this area; there is about 5 per cent of timothy and the amount of entire vegetation is 57 per cent of Kentucky bluegrass. White clover has gained considerable area in this section of field.

In 1912 the 21 plots receiving the high potash fertilizers, that is the area marked by plots 56, 16 and 61, contained the three grasses, timothy, Kentucky bluegrass, and Canada bluegrass in the proportion of 28, 28 and 44 per cent, respectively. An examination of figure 1, circle 68, giving the average composition of the grasses of these 21 plots in 1916, shows that Canada bluegrass has practically disappeared. Examination of the 21 plots in the diagram shows that it has disappeared in all but two of these plots. About 10 per cent of the entire area is timothy, and 44 per cent Kentucky bluegrass White clover has increased in this area.

From a study of the records of this experiment it would seem that in fertilizing a pasture containing mixed vegetation such as prevailed in this field, nitrogen is especially favorable to growth of Kentucky bluegrass, aiding it in its struggle for existence against its competitors. The relative amount of this variety is greater in the high nitrogen than in the high phosphate or high potash plots. This is seen by a general examination of the chart of figure 5 and also by circle 69, which shows the average composition of the 21 mainly nitrogenous plots after 7 years of fertilization. Timothy has prevailed in only a few of the plots in the nitrogen end of the triangle. In this experiment timothy has stood the struggle for existence best where fertilizers high in potash were used, this is shown in circle 68, which gives the average composition of the 21 mainly potassic plots. Canada bluegrass which was the prevailing grass when the experiment was started has disappeared in all but two plots, which shows that the conditions of this field resulting from fertilization or management are not suitable for this variety.

Clover. As seen in plate 2, fig. 1, only a small amount of clover prevails in the nitrogen end of the triangle, white clover is found more abundantly than red clover, in fact red clover has become extinct in all but one of the mainly nitrogen plots. Clover becomes more abundant as one proceeds from the nitrogen end of the triangle to the section of the field which receives

decreasing amounts of nitrogen, either in the direction of the phosphate or potash end.

Looked at from the point of view of the nitrogen content of the fertilizer, clover is more abundant in the line of plots 1–56, which receives mixtures of phosphate and potash, but no nitrogen, than any other set of plots. The next line of plots 3–57 which receives fertilizers containing in the mixture only 5 pounds of NH_3 are next in order from the point of view of the prevalence of clover. The dominance of clover becomes still less in the third line of plots 6–58, which receives fertilizer mixtures containing 10 pounds of NH_3, and likewise as one approaches those plots in the order of the increasing amount of nitrogen in the fertilizer mixture, the amount of clover is observed to decrease.

The extinction of red clover in the high-nitrogen plots and its prevalence in those plots fertilized with a mixture containing none or only a relatively small amount of nitrogen seems significant. It will be noticed that red clover is still found in almost all of the plots receiving a fertilizer mixture low in nitrogen.

Looked at from the point of view of the mainly nitrogenous, mainly phosphatic and mainly potassic plots it is seen that in the 21 mainly nitrogen plots, red clover has disappeared in all but one plot, but white clover still prevails in all but three. The average composition of the vegetation of these 21 plots has 16 per cent of white clover. The average composition of the vegetation of the 21 mainly phosphatic plots is 32 per cent white clover and 5 per cent red clover. In the 21 mainly potassic plots there is 32 per cent of white clover and 12 per cent of red clover.

SOUTH TRIANGLE

Grasses. The South Triangle presents a picture somewhat similar to the North Triangle when the percentages of the different species of grasses and clover, are charted in colors, as shown in plate 2, figure 2. Here again it is apparent that the grasses, and especially Kentucky bluegrass, predominate in the plots in the nitrogen end of the triangle. Proceeding from the nitrogen end of the triangle, the clover is more abundant.

In 1912 the 21 mainly nitrogen plots, as a whole, contained the grasses, timothy, Kentucky bluegrass and Canada bluegrass in the proportion of 5, 30 and 65 per cent, respectively. The average composition of the grass of these 21 plots as noted in 1916 is shown in circle 69 of plate 2, figure 2, where it is seen that 10 per cent of the entire vegetation is timothy, 60 per cent Kentucky bluegrass, and only 5 per cent Canada bluegrass. In these plots receiving fertilizers of high nitrogen content, timothy has increased slightly, Kentucky bluegrass has gained considerably, and Canada bluegrass has become almost extinct.

In 1912, timothy, Kentucky bluegrass, and Canada bluegrass prevailed on the 21 mainly phosphatic plots, in the proportion of 5, 20 and 75 per cent,

respectively. The average composition of the vegetation of these plots in 1916, as shown in the circle 67, plate 2, figure 2, is 5 per cent timothy, 40 per cent Kentucky bluegrass and 10 per cent Canada bluegrass. In these plots both timothy and Canada bluegrass still prevail in appreciable amounts. There is slightly more timothy, a large increase in Kentucky bluegrass, and a great decrease in Canada bluegrass.

The three grasses, in the 21 mainly potassic fertilizer plots in 1912, were timothy 17, Kentucky bluegrass 33 and Canada bluegrass 50 per cent. In 1916 the timothy has increased, 20 per cent of the entire vegetation being of this species, 40 per cent being Kentucky bluegrass, and 5 per cent Canada bluegrass.

Again in this experiment it is apparent that Kentucky bluegrass has become the predominating species. It is also apparent, as in its companion experiment, that the fertilizer mixtures high in nitrogen are especially favorable for the dominance of this species over other grasses and clover. This is seen by an examination of the circles within the sub-triangle 21–61–66 comparing them with the other circles of the triangle. It is also seen by an examination of circles 67, 68 and 69. Circle 69 gives the average composition of the vegetation of the 21 mainly nitrogenous plots.

Timothy is found in most of the plots, having been crowded out in only a few. It occurs in larger proportions in the plots receiving a fertilizer high in potash, which like the first experiment discussed, seems to show that this species can exist best in a pasture of mixed vegetation under such fertilization The timothy has increased somewhat in the potash section of the triangle.

Canada bluegrass is losing ground rapidly; it still occurs in a number of plots in different parts of the triangle, occurring less frequently in the potash section.

Clover. The prevalence of clover in the variously fertilized plots in 1916 in this triangle is very much the same as in the experiment already discussed. In the plots in the nitrogen end of the triangle there is a relatively small amount of clover, especially red clover. Both the red and white clover increase in the plots as the nitrogen decreases. White clover is most prevalent on the no potash plots and on the plots in the interior of the triangle, where the fertilizers applied contained nearly equal proportions of the three constituents. The red clover is most abundant again in the line of plots receiving no nitrogen and in the next line of plots which receives only 5 pounds of NH_3 in the fertilizer applied. In the circles 67, 68 and 69 in plate 2, figure 2, it is again seen that there is more clover in the phosphate and potash than in the nitrogen plots. The two experiments agree in showing that the growth of clover in mixed herbage has less chance for existence under conditions of high nitrogen fertilization, this being especially true of red clover. Red clover, in fact, has dominated most in both experiments where the fertilizer mixture used contained phosphate and potash, and no nitrogen, or in a mixture of the 3 constituents containing only a small proportion of nitrogen.

THE INFLUENCE OF FERTILIZER ON THE REACTION OF THE SOIL

The lime requirement of the soil from each individual plot was made, on samples taken in the fall of 1917. The reaction of the differently fertilized plots varies greatly, and some interesting results were secured. The determinations were made by the Veitch method (4) on a sample, secured by taking 5 borings from each plot with a soil auger. The data are given in figure 4, in pounds of CaO per acre required to neutralize the first 7 inches weighing 2,000,000 pounds.

The most striking feature about these results is that the plots which received mixtures of acid phosphate and potassium chloride, but no sodium nitrate have the greatest lime requirement. This is seen by observing the figures of the no nitrogen plots, that is the line of plots 1–56 (pl. 1). The next line of plots, 3–57, which receives a mixture of the three fertilizers containing only 5 pounds of NH_3 as sodium nitrate have a lime requirement less than those where no sodium nitrate is contained in the fertilizer mixture, but greater than the line of plots which receives 10 pounds of NH_3 as sodium nitrate in the mixture. In the section of the triangle which receives small amounts of sodium nitrate, and in the center, where the fertilizer mixture is well balanced, that is, contains about equal proportions of the 3 constituents, the soil is either neutral or has a very low lime requirement. The result with the sodium nitrate is probably due to the utilization of nitrate by the growing crop, leaving the base, sodium, an accumulation of which would tend to cause an alkaline condition in the soil. It was shown by one of us that sodium nitrate continually applied to the Susquehanna silt loam on the Arlington Experimental Farm, prevented the soil from becoming as acid as untreated soil, in fact, it is commonly accepted that soils fertilized year after year with sodium nitrate, become alkaline and assume a bad physical structure (3).

The neutral character of the plots fertilized with sodium nitrate, or a well-balanced fertilizer of nitrate, phosphate and potash , may possibly be due to the biological changes in the soil produced by such fertilization.

DISCUSSION AND SUMMARY

The results of a fertilizer experiment on grass on the Hagerstown loam soil, which has been conducted for 7 years are reported. The fertilizers used are acid phosphate, sodium nitrate, and potassium chloride. Each fertilizer was used alone, and in combination of twos and threes, the ingredients varying in 10 per cent stages. In all there were 66 treatments, as outlined in the triangle scheme of fertilizer experimentation. The total amount applied on each plot annually was 50 pounds per acre of the fertilizer elements P_2O_5, NH_3, or K_2O.

The plots are located in a pasture field where the composition of vegetation was originally Canada bluegrass, Kentucky bluegrass, timothy, and white and red clover. At the end of 7 years the differently fertilized plots contained

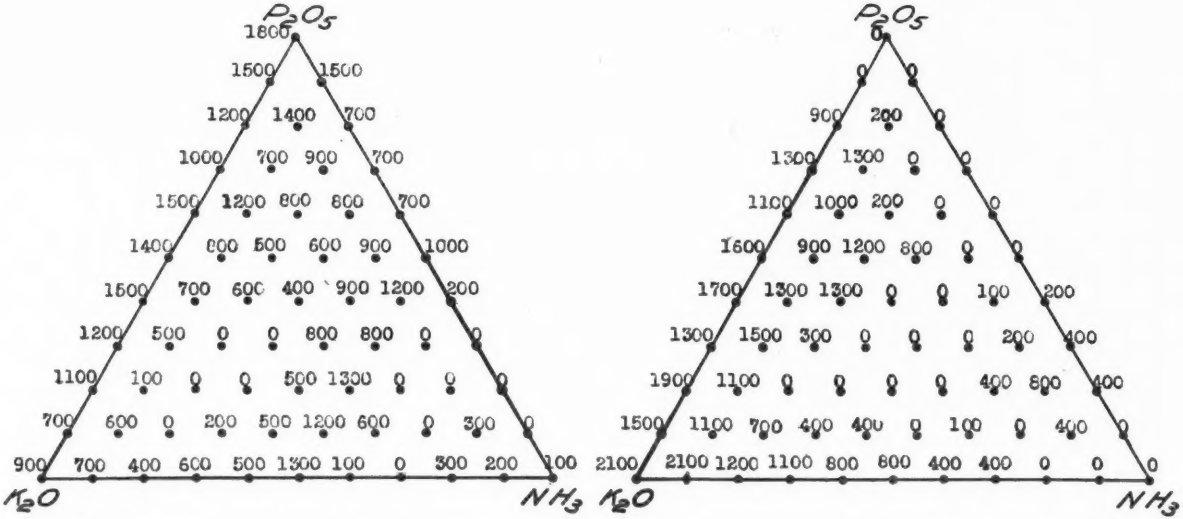

FIG. 4 LIME (CaO) REQUIREMENTS OF PLOTS OF (1) NORTH AND (2) SOUTH TRIANGLE, IN 1916, AFTER 7 YEARS OF FERTILIZATION, EXPRESSED IN POUNDS OF CaO REQUIRED TO NEUTRALIZE AN ACRE 6 INCHES

Note that the lime requirement of the high nitrogen plots is small, or neutral, whereas the plots receiving fertilizer mixture of low nitrogen ratios are higher, the lime requirement increasing as the sodium nitrate in the mixture decreases.

the various species in distinctly different proportion. Kentucky bluegrass has become the predominant variety, while in the beginning Canada bluegrass prevailed in larger proportion. Complete fertilizer mixtures high in nitrogen seem especially favorable for the dominance of Kentucky bluegrass over its competitors, while it is indicated that timothy is somewhat more favored by the fertilizers high in potash.

Grass generally has predominated over clover in the plots receiving fertilizers with high ratios of nitrogen, while clover and especially red clover has been crowded out of such fertilized plots. Clover has existed in the struggle for existence most easily in the plots fertilized with mixtures of phosphate and potash with no, or only a small amount of, nitrogen. The largest amount of clover occurs in the no nitrogen series of plots, and decreases in the plots as the nitrogen content of the fertilizer increases. This is very marked in the case of red clover.

The soil of the plots receiving well-balanced mixtures of acid phosphate, sodium nitrate and potassium chloride, or mixtures containing principally sodium nitrate tends to remain neutral or become alkaline, but where no sodium nitrate or only a small proportion is in the mixture the soil became acid. The lime requirement increases as the proportion of sodium nitrate in the fertilizer mixture used decreases.

It might be interpreted from these results that clover has stood the struggle for existence better in the plots which have become acid. However, this condition probably is not due to the reaction of the soil, but is due in part to the supremacy of Kentucky bluegrass in this section of the triangle where the fertilizers supplied the needed nitrogen for the grass and it succeeded in crowding out the clover. The conditions in the no nitrogen section of the triangle, were unsuited to grass, the clover predominating as it supplied its own nitrogen supply through root nodules.

The most acid plots are not sufficiently acid to prevent the growth of clover in this soil. White (5) has shown that red clover grows best in this soil when limed, the maximum yield was secured when limestone was applied at the rate of 3 tones per acre in excess of neutrality. Clover failed in field and in pot experiments where the lime requirement reached 3,000 to 3,500 pounds per acre. From the data in figure 4 it is seen that the lime requirement of the most acid plots is far less than these amounts found by White in his work on the Hagerstown loam. The predominance of species found to exist after 7 years of fertilizer application, is more probably due to the survival of that species for which the existing fertilizer treatment is best suited.

At the beginning of the experiment the dominant species was Canada bluegrass, while at the end of 7 years this grass generally has given way to Kentucky bluegrass, this variety now being the dominant grass, which may possibly be due to a superior power of endurance in the plant itself compared with its competitor, rather than to directly favorable conditions of fertilization. Other species are dominant on some plots, entirely absent in others,

or exist only in small proportion in still others. In such cases it may be assumed that the particular fertilizer has been either directly favorable to the species, or indirectly so by being prejudicial to the growth of others. If any one species be dominant on a group of plots more or less similarly fertilized, the inference is that the fertilizer is directly beneficial to that species.

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PLATE 1

The Fertilizer Ratios Used in the Grass Experiment, are Shown Here by the Triangular Diagram

There are 66 fertilizer mixtures, the constituents, acid phosphate, sodium nitrate and potassium chloride are used singly, in combination of twos, and in combinations of threes, the ratios of P_2O_5, NH_3, and K_2O vary in 10 per cent stages. Fertilizers were applied annually in amounts of 50 pounds per acre of P_2O_5, NH_3 or K_2O.

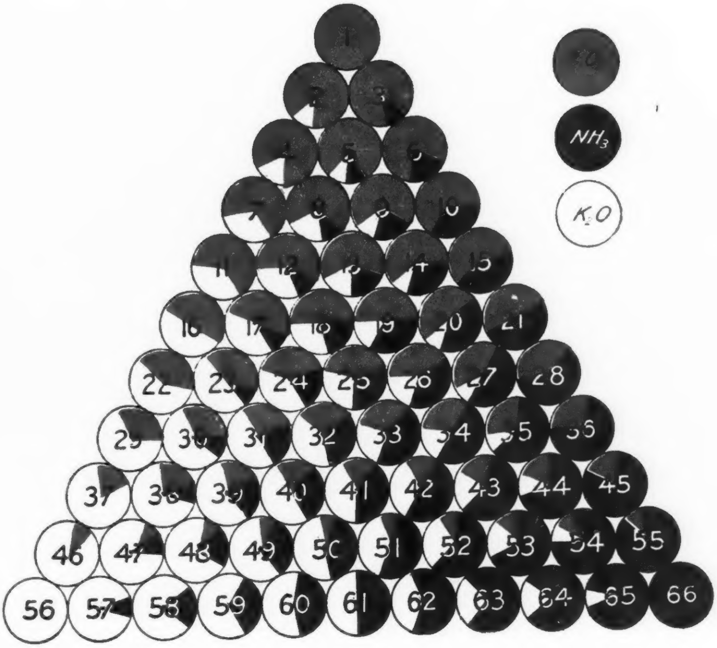
NH_3
K_2O

PLATE 2

FIG. 1. DIAGRAM SHOWING THE EFFECT OF FERTILIZERS, CONTAINING THE CONSTITUENTS, ACID PHOSPHATE, SODIUM NITRATE AND POTASSIUM CHLORIDE IN DIFFERENT RATIOS ON THE BOTANICAL COMPOSITION OF THE VEGETATION OF A PERMANENT PASTURE, AFTER 7 YEARS OF FERTILIZER TREATMENTS, IN THE NORTH TRIANGLE

Note that Kentucky bluegrass predominates in the nitrogen end of the triangle, and that this section contains almost no clover. Clover and especially red clover is more prevalent in the no nitrogen section of the field. Circle 67 shows the average composition of the 21 mainly phosphatic plots (sub-triangle 1–16–21), no. 68 the average composition of the 21 mainly potassic plots (sub-triangle 16–61–56), and no. 69 the average composition of the 21 mainly nitrogenous plots (sub-triangle 21–61–66).

FIG. 2. DIAGRAM SHOWING THE EFFECT OF FERTILIZERS, CONTAINING THE CONSTITUENTS, ACID PHOSPHATE, SODIUM NITRATE, AND POTASSIUM CHLORIDE IN DIFFERENT RATIOS ON THE BOTANICAL COMPOSITION OF THE VEGETATION OF A PERMANENT PASTURE AFTER 7 YEARS OF FERTILIZER TREATMENT, IN THE SOUTH TRIANGLE

It is also seen here that grass is the prevailing species in the plots receiving fertilizers with high nitrogen ratios, while clover has become almost extinct. Clover is again found more abundantly in the no nitrogen plots, and in the plots receiving fertilizer mixtures of a low nitrogen ratio. Circle 67 shows the average composition of the 21 mainly phosphatic plots (sub-triangle 1–16–21), no. 68 the average composition of the 21 mainly potassic plots (sub-triangle 16–61–56), and no. 69 the average composition of the 21 mainly nitrogenous plots (sub-triangle 21–61–66).

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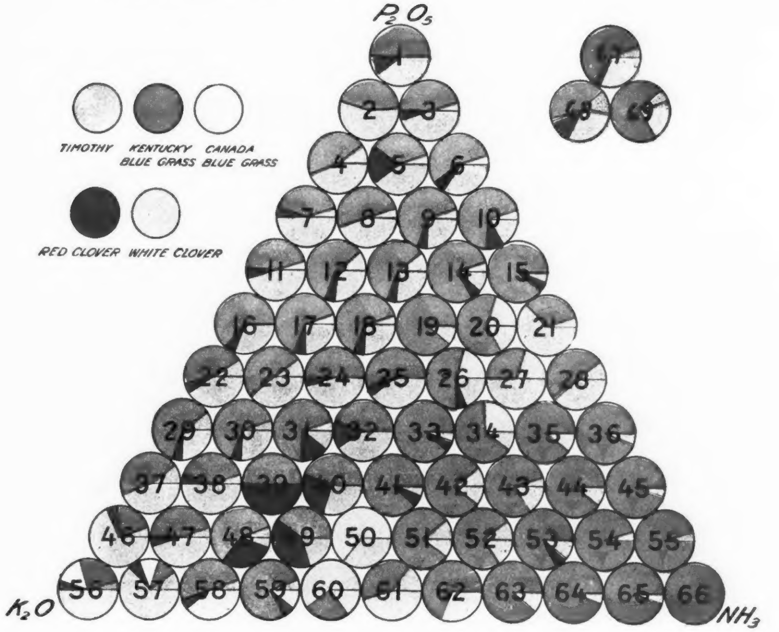

FIG. 1

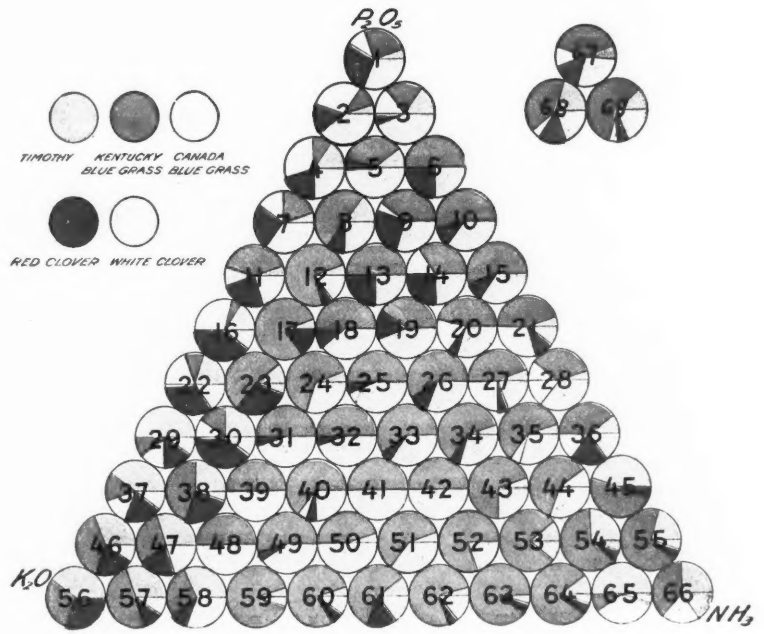

FIG. 2